

**SOME PERFORMANCE ASPECTS OF SEED MAIZE
PROCESSING OPERATIONS**

BY
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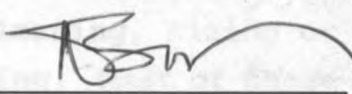
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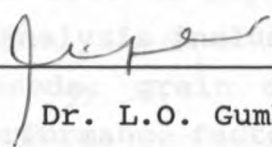
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DECLARATION

I declare that this is my original work and has not been presented for a degree in any other University.

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ABSTRACT.

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SEED MAIZE PROCESSING OPERATIONS.

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The processing of seed maize includes such activities like drying, shelling, cleaning, sizing or grading, chemical treatment and bagging. Most of these unit operations are capable of affecting the quality of seed if proper control is not instituted. The objective of this thesis is to analyse some performance aspects of an existing commercial seed maize processing plant of the Kenya Seed Company Limited. A good portion of this work has dealt with drying and damage to seed during shelling since it was felt that the two areas are more critical in the present situation. Various recommendations are suggested that can further improve the performance of the seed processing plant.

The field tests were carried out at Seed Driers Limited in Kitale between November 1989 to September 1990. The parameters used in the analysis include the germination capacity of dried seeds, grain damage through mechanical shelling and performance factors of cleaning and sizing operations.

The results obtained show that maize ears dried at the top and those dried at the bottom of the bin behave differently when their drying curves and germination are compared. No statistical significance was found when the effect of sheller speed on grain damage was considered even though certain varieties tend to generate more damaged seeds after processing. Hybrid variety number 512 produced the largest amount of chipped grains, while varieties H625 and H614 generated more screenings.

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Let me also acknowledge JKUCAT for granting me study leave and scholarship for the entire study period at the Department of Agricultural Engineering of the University of Nairobi. There are numerous other people who have contributed in diverse ways for the success of this work, only space limits specific mention of their names. Thank you.

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ABBREVIATIONS AND SYMBOLS.

- SCALP. - Carter Scalperator.
- F.AS. - Fractionating Aspirator.
- CPG - Carter Precision Grader.
- R - Round Hole Screen Perforation.
- S - Slotted Screen Perforation.
- SDL - Seed Driers Limited.
- LF - Large Flat.
- MF - Medium Flat.
- HP - Hand Planting.
- R_j.1 - Large trash from scalper.
- R_j.2 - Small, chipped and broken grain.
- R_j.3 - Light rejects from F.AS.
- 27R, 14S, etc. - Size of perforations in 64ths. in.
- M - Moisture concentration.
- Moisture content (db) at any time, t
- D_j - Diffusivity of material j.
- c - Constant, zero for planar symmetry, unity for cylindrical body and 2 for a sphere (Eqn 4.1)
- MR - Moisture ratio, dimensionless.
- M_o - Initial moisture content (db)
- M_c - Equilibrium moisture content (db)
- k - Drying parameter

(Key to figure 5.5, page 79)

- AS - After sheller
- AP -After pre-cleaner
- 30R -Screen size 30/64", Round holes
- 27RO -Over screen size 27/64", Round holes
- 27RT -Through screen size 27/64", Round holes
- 24RT -Through screen size 24/64", Round holes
- 14SO -Over screen size 14/64", Slots
- 14ST -Through screen size 14/64", Slots
- HPH,MFH,LFH -Hand plant, Medium flat and Large flat from hopper
- HPD,MFD,LFD -Dressed varieties of Hand plant, Medium flat and Large flat

1.0 INTRODUCTION

In this section, the importance of maize in Kenya agriculture is presented. A brief historical background of hybrid maize production by the Kenya Seed Company is also given. The subject of seed quality control is also discussed in terms of germination rates and purity of the seeds.

1.1 Maize in Kenyan agriculture

The importance of maize (or corn) in Kenya when considered in terms of its monetary value, its planted acreage and its role as a basic dietary staple has been well documented (Muthoka, 1988; Ogutu, et al. 1990; Kakuba, 1986; Gerhart, 1975 and Rundquist, 1984). Improved varieties now occupy over 60% of the area planted with maize, most of which are hybrids. The national average has also gone up from 1.0 tonne per hectare before 1960 to 1.9 tonnes in 1986. Kakuba (1986) reports that the majority who have contributed to this increase are small scale farmers who on the average plant less than 20 hectares. Rundquist (1984) also observed that a major share of the maize produced by small scale farmers is for home consumption.

1.2 Seed production by Kenya Seed Company.

Seed maize production in Kenya has largely been carried out by the Kenya Seed Company (KSC) which was formed in 1956 mainly to cater for farmers' demand for improved pasture seed (Combes, 1974). Average annual production currently stands at approximately 22000 tons.

For production of certified seed, the Kenya Seed Company contracts with selected growers of which 35% are ADC farms and 65% are individuals. Seed Driers Limited, which is a subsidiary company of KSC performs the bulk of processing operations. It accepts maize seed once it is physiologically mature, dries it on the cob using hot air before shelling and grading. All the seed conditioning operations are located in one place to effectively carry out the above mentioned operations.

1.3 Quality in seed processing.

As outlined in Section 1.2 above, the processing of maize for seed takes place by first drying on the ear before shelling, cleaning, sizing, treating and bagging. The quality of seed is frequently measured in terms of percentage germination according to the standards set up by such organizations like the International Seed Testing Association (ISTA). Ghaly et

al. (1982) and Nellist (1978) observed that the germination test is still being widely used as a criterion for rating acceptability of cereal grains for milling and baking. Heated air drying has also been recognised as a major quality reducing factor in seed processing, especially if there is no careful control of temperature, relative humidity, air flow rate and the drying time (Brooker, et al. 1982; Nellist, 1981; ASAE (1987); Bras, 1982). The development of new varieties, changing agronomic practices and the installation of new drying processes have resulted in a need for information and surveys on the quality of Kenyan maize for planting and human consumption. Mechanical shellers and cleaning equipment can cause much damage to seed which is otherwise of good quality by other standards. Concealed damage in the form of stress cracking, as defined by Gunasekaran (1987), can also greatly lower the germination percent of the maize. Arising out of lowered germination percentage due to poor processing is the loss of goodwill from the farmers. The International Seed Testing Association sets 90% germination as the lower limit for any seed maize meant for sale. The US Department of Agriculture has also set up grade standards for commercial maize as shown in Table 9-2. According to Woodstock (1973), point measurement of germination and vigour tests

should be an integral part of quality control in a seed industry. Proper analysis for both qualitative and quantitative losses is necessary for effective operation of a seed plant and this should be systematic in its approach. Such a method of sampling from point to point along the processing line was done during data acquisition at the Seed Driers Limited.

Nellist (1982) mentioned four pertinent factors that affect seed viability and these determine the drying behaviour of such crops:

- (i) The initial quality of the seed.
- (ii) Grain temperature during drying.
- (iii) Moisture content of grain at any time.
- (iv) Exposure time during drying.

The position of the maize ears in the drier also affects quality parameters already mentioned. The incorporation of the four parameters above also requires accurate mathematical description of the drying processes. Incidences of over-drying, under-drying, fissuring or stress cracking of grain can go unnoticed if an attempt is not made to establish their occurrence or absence.

1.4 Objectives.

The effect of conditioning processes on seed quality has been outlined above. The objective of this study is to evaluate the performance of an existing seed maize drying and processing plant of the Kenya Seed Company. Specific objectives are to:

- a) Study the effect of drying process on germination of different maize seed varieties.
- b) Establish drying parameters for such varieties.
- c) Analyse and quantify the level of mechanical damage and other seed losses during drying, shelling and cleaning.

2.0 LITERATURE REVIEW.

Under this section, various aspects of seed maize conditioning are reviewed. Pre-conditioning processes, handling within the plant and the final seed preparation methods designed to meet consumer needs such as cleaning, sizing, dressing, and bagging are lumped up under the sub-heading " Seed Processing". Due to the importance of drying in seed industry, its effects on quality are included. The criteria used for measuring seed quality such as germination, 1000-seed weight and percentage of mechanical damage are also reported.

2.1 Seed Processing.

The processing of seed has been variously defined depending on the nature of the operations involved and the type of crop seed involved (Combes, 1974; Hazelden, 1982; Kelly, 1989; Rono, 1989; Feistritz, 1982; Thomson, 1979). Generally when seeds are brought from the field they contain undesirable materials such as pieces of stem, dust, weed seeds, other crop seeds and off-size, discoloured, broken and otherwise impaired units of crop seed. The following operations, as outlined by Rono (1989), form the basic maize seed processing or conditioning (see Figure 2.1):

- a. Receiving seed
- b. Drying seed
- c. Shelling and Pre-cleaning
- d. Basic cleaning of seed
- e. Sizing and upgrading of seed
- f. Seed treatment and packaging

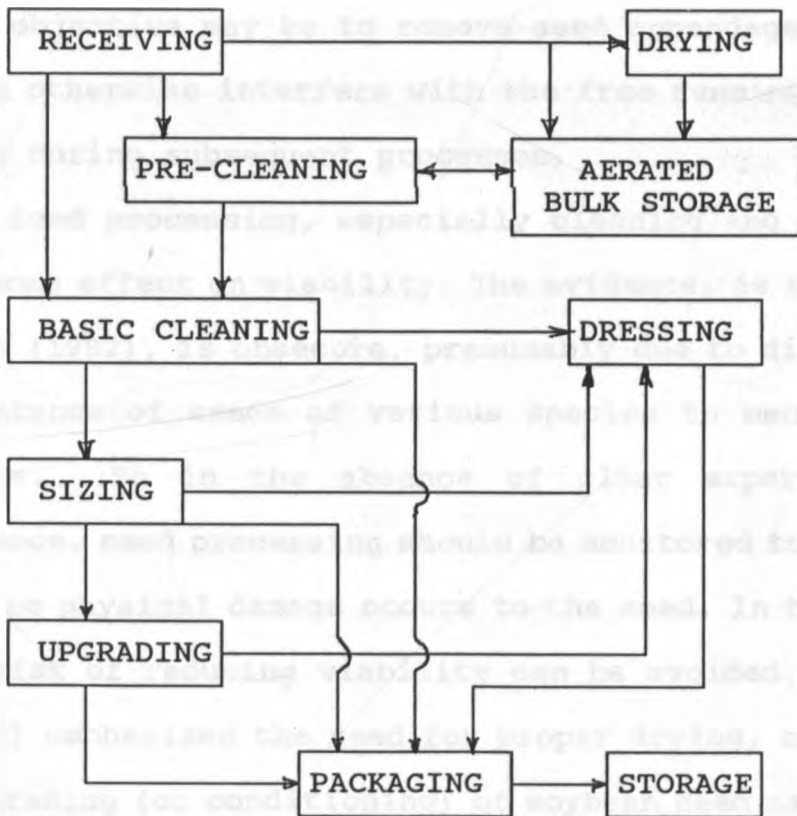


Figure 2.1 Steps in seed conditioning and alternate pathways among steps. (Source: Boyd and Potts, 1983)

As outlined in the previous page, preparation of seed after harvest involves a series of mechanical operations designed to remove undesirable materials, treatment with chemicals and suitable packaging of the seed for distribution and marketing. George (1985) observed that in the seed industry in general, the term "seed processing" is used when a wide range of operations are employed to improve or upgrade seed lots after threshing or extraction. In other instances, the main objective may be to remove seed appendages which would otherwise interfere with the free running of the seeds during subsequent processes.

Seed processing, especially cleaning and sizing, has some effect on viability. The evidence, as noted by Smith (1982), is obscure, presumably due to differing resistance of seeds of various species to mechanical damage. So in the absence of clear experimental evidence, seed processing should be monitored to ensure that no physical damage occurs to the seed. In this way any risk of reducing viability can be avoided. Misra (1982) emphasized the need for proper drying, cleaning and grading (or conditioning) of soybean seed mainly to achieve acceptability in the market. This contention is true to some extent since proper agronomical practices will undoubtedly lead to high quality seed. However, Misra (1982) further recognised that the benefits of

high purity and disease-free seeds can be reduced by poor handling and conditioning. Locations at which reduction in seed quality occurs in a processing plant can be identified by analyzing samples at each step of conditioning and can be a valuable tool in quality control.

2.1.1 Steps in seed conditioning.

Diligent observation of the harvested maize seed ears by trained personnel is essential for the removal of off-type ears (or different varieties) and those which are mechanically damaged or diseased. Much of the undesirable materials which can easily be sorted out in the field need not reach the processing plant. Once the crop has been delivered for processing, visual ear sorting (selection) is necessary. At this stage Potts (1984) recommended that typical examples of off-type ears and male ears be on display as a visual guide for manual ear sorting. These examples should be adjusted for each new variety being harvested. Boyd et al. (1983) listed the following as the basic steps in seed conditioning:

- (1) **Receiving** and storage capability should be adequate for the expected rate of receiving. A facility receiving seed in bulk at harvest time should have a dump pit/elevator storage bin combination large enough to hold at least an average truck load. It is important

that dump pits be lined with special rubber cushions so as to reduce the impact damage of the wet ears.

- (2) **Drying** is important at any time because seed is harvested at moisture contents higher than that which would allow safe storage. Baskin (1984) indicated that temperature is very critical in drying seed. Underdrying results in seed of moisture content too high to store safely. Over-drying can cause quality losses in mechanical damage, even seed death resulting in weight and monetary loss.
- (3) **Pre-cleaning** is useful when there is large amount of trash or green wet material in the seed. Precleaning prior to drying can result in greatly enhanced capacity of driers and less resistance to air flow during drying. It also allows more precise screen selection during basic cleaning. Shelling is a special case of preconditioning in maize and significant losses can be experienced in terms of cracked seeds.
- (4) **Basic cleaning** is accomplished by the air-screen cleaner which has a series of screens and air separations to remove light trash, dust and undesirable materials both larger and smaller than the crop seed.
- (5) **Sizing** or upgrading machines utilize various physical characteristics of the seed to effect the desired separations, e.g. medium flat, large flat and hand plant.

- (6) **Treating** also referred to as "dressing" may include the application of fungicides, insecticides and/or other materials such as growth regulators, etc. Seed is not always treated prior to the packaging step. This is partly because of any need that may arise prompting the sale of seed for human consumption. Again if seed is of very low quality, then it is wise not to further spoil it with chemicals. Treated seed cannot be sold otherwise. Untreated seed can be released from storage and treated as the need for marketing arises.

2.1.2 Handling damage.

Stephens and Foster (1976) conducted a series of tests to determine the relationship between breakage in a Stein Breakage tester and actual breakage due to handling. They used three batches of corn which had been given different drying treatments. The samples were elevated 48m. by a bucket elevator and dropped through a spout into a truck. The authors found out that the ratio between the Stein breakage and actual breakage due to this handling to be about 6:1. Herum and Hamdy (1981) evaluated the ability of several breakage testers to predict corn breakage resulting from passage through a full scale elevator. They cycled shelled maize eight times through a bucket elevator, U-tube augers and gravity drops into 213 m³ capacity tanks. Breakage was measured using three testers: Stein

CK-2M, a modified Stein and a centrifugal impact tester. The ratio between average breakage for all three testers and actual breakage due to handling was about ten to one. Jenkins et al. (1984) developed a technique for measuring impact damage under varying impact velocity and surface conditions. They concluded from their investigations that for minimum impact damage considerations, belt speed should be kept to a minimum. Damage was also found to be independent of product loading density (which is the number of product specimens per given length of belt). Loading rate increases in bin filling operations should therefore be effected through loading density increases as opposed to increasing belt speed. Fluck and Ahmed (1973) examined the concept of mechanics such as conservation of energy and momentum in relation to impact of fruits and vegetables. Their study sought to identify the impact parameters (velocity, energy, force, etc.) that are associated with damage. Their conclusion was that as relative velocity of impact increased, peak deceleration, peak force and impulse increased while duration of impact continued decreasing.

Hall and Johnson (1970) also studied crackage of maize kernels induced by mechanical shelling in combine harvester cylinders. They did their analysis by counting the number of damaged kernels or getting the

percent by weight that passed through a 12/64" round hole screen. Waelti and Buchele (1969) (cited by Hall and Johnson, 1970) found that kernel damage was positively related to kernel moisture by the relationship, $Y = ax + b$, where Y is the common logarithm of damage and x is also expressed as the common logarithm of moisture content for the moisture range of 15 to 38 percent. Moreira et al. (1981) also investigated the formation of internal cracks in maize kernels due to impact loading at three different levels of moisture content, impact velocity and orientation. They found out that the percentage of internally cracked kernels increased with an increase in velocity and a decrease in moisture content. Side and corner orientations of impact were found to produce the most internal cracks in maize kernels. Moreira et al. (1981) further concluded that most cracks were formed when 13.4% moisture corn was impacted at a velocity of 18 m/s. Cracks were also observed at velocities as low as 10 m/s. While studying the characteristics of corn failure, Johnson et al. (1969) reported that the energy per kilogramme of kernels removed increased as moisture content increased, because the ears with higher moisture absorbed more energy before they failed. Anazodo et al. (1981) studied various physical properties of maize as related to combine cylinder

performance. Cob break-up, shelling percentage and kernel damage (also investigated in this work) were some of the parameters measured in a stationary rasp bar cylinder. Cob crushing strength, determined as the maximum contact stress under radial compression, was found to be the most important single crop property influencing shelling in the conventional combine cylinder.

The effect of mechanical stress on seed maize quality during processing was also investigated by Leist et al. (1978). They observed that flat seeds of dent maize tolerated more mechanical stress than the flint type, but still up to 20% of the seeds were damaged. Close correlation was found between germination, seed injuries (cracks and detached top of the seed) and the exposed position of the embryo. Martin et al. (1987) also investigated the effect of size and shape on breakage susceptibility and hardness of corn kernels. One of their conclusions was that large round kernels were consistently the most susceptible to breakage while fine breakage and moderate breakage were influenced by kernel size, shape and structure.

2.1.3 Stress cracking in maize.

While studying the consequences of drying processes on the physical appearance of grain, Bras (1982) reported that before drying, the grain is always in thermic and hydric equilibrium. During its journey in the drier, it will undergo a more or less brutal desiccation. The water around the grain evaporates rapidly and the desiccation will then depend on the speed with which the water in the interior of the grain migrates to its peripheral zone. An internal growing moisture gradient builds up from the exterior to the interior of the grain. This gradient's intensity is stronger if the hot air temperature is high and the grain gets rid of its water with less ease. The temperature and moisture gradients so formed create internal tensions in the grain. The mechanical tensions cause cracks in the kernel which facilitate the desiccation in the final stages. Cracks make grain fragile and more sensitive to breakage during later handling. Kunze (1979) made extensive studies on the fissuring of rice and observed the same mode of stress development. White et al. (1980) agreed with Thompson and Foster (1969) that stress cracks in popcorn tend to develop long after drying is completed as depicted in Table 2-2.

Table:2-2 Percentage of popcorn kernels with stress cracks.

Time after removal from drier (hrs)	Average MC. when removed from drier			
	16%	14%	12%	10%
0	0	0	0	5.5
2	0	-	74.3	86.3
4	0	1.4	97.3	---
6	0	68.6	97.3	---
8	0	75.7	98.6	---
10	0	85.3	98.6	93.2
12	1.5	92.9	98.6	97.3
18	1.5	92.9	98.6	98.5
24	1.5	92.9	98.6	---

(Source: White et al.1980).

Gunasekaran et al. (1987) defined stress cracks as very fine fissures in kernel endosperm underneath the pericarp. They reported that physical stresses developed in corn kernels as they are harvested, dried, stored and processed cause various quality defects. Stress cracks caused by a combination of thermal, moisture and mechanical stresses are internal and not readily identifiable. Using scanning electron microscope pictures, Gunasekaran et al. (1985) concluded that a typical stress crack is about 53µm in

width and half the kernel thickness in depth. The cracks were also found to propagate from the centre of the kernel and may not extend to the surface underneath the pericarp. This subject of stress cracking has been investigated by several other researchers (Balastreire, 1982; Hammerle, 1972; Okos, 1982; Rao, 1975; Ekstrom et al., 1966; Herum et al., 1979; Okos et al. 1982). Waananen et al. (1988), in particular took a theoretical approach to the study of drying induced kernel stresses. Some of the methods which have been used for examining stress cracks include candling the kernels with bright light source (Moreira, 1981), light reflectance using neon laser, laser optics, ultrasonic imaging which involves slicing the kernels into thin sections and optical imaging which requires the use of a computer vision system. These techniques are increasing in complexity and their widespread applicability in seed quality analysis may be hampered due to cost. X-ray techniques have also been used for evaluating internal damage in Navy beans by Hoki et al. (1973), in wheat by Chung, et al.(1970), in rice by Mathews, et al. (1981) and in maize by Eneh (1981) and Moreira et al. (1981). The latter researchers could not obtain good resolutions with the X-ray technique after trying a variety of settings. However, Chung et al. (1970), explained that radiographical examination of

grain is useful in predicting quality of grain, in studying the structure of cereal grain kernel, and in explaining the mechanisms and rate of moisture movements in kernels for engineers who are concerned with handling, storage and processing of grain. Foster and Thomson (1961), as quoted by Shove, et al. (1977), even suggested that since the viability of dried corn samples decrease as the number of kernels with stress cracks increase, stress cracks evaluation might provide a faster test than the germination tests used for determining the effect of drying on corn being considered for wet milling and other commercial uses.

2.1.4 Cleaning, sizing and dressing of seed.

When seed has been dried and mechanically shelled, the next step is cleaning. Kelly (1988) has stated two objectives of cleaning seed: (i) to remove seeds of species other than the crop species and inert matter and (ii) to select from within the crop seed a finished product graded as to size from which light, discoloured or otherwise unhealthy seed has been removed. Seed cleaning cannot be performed satisfactorily on a rule-of-thumb basis, since each seed lot presents problems which have to be analyzed and solved by using particular machines adjusted in particular ways. The standard of cleaning to be achieved mainly depends on

the desired product. Work reported by Combes (1974) indicate that the extent to which separations can be made using screens depends on the size of the seed relative to the unwanted material, the size and shape of the perforations in the screen, the speed and distance travelled at each "shake" and the length of time the seed is subjected to the screening process.

Seed may be treated before sowing for several different purposes :

1. Seed disinfection is intended to combat seed borne pests and diseases.
2. Seed protection is intended to protect the seed against the pests and diseases which may be present in the soil or air-borne when the seedlings emerge.
3. Seed coating is a way of adjusting the size of irregularly shaped seeds to make them easier to grow.

It is important to treat seed just before it is needed for sowing so that it is not stored for long periods after treatment. This minimises the risk of damage to the germination capacity and also the fact that excess seed may be used as food for humans or animals.

2.2 Ear maize drying.

Convection drying of biological products at moderate temperatures during the falling rate period has been the subject of many studies, some of which have been reported by Huizhen, et al. (1984). Mathematical models describing drying characteristics of fully exposed objects have also been developed with varying degrees of success (Sharaf-Eldeen, 1980). Most researches have concentrated on the drying of shelled maize in thin layers. However, Barre (1963), cited by Sharaf-Eldeen et al. (1980), observed that ear maize drying is exclusively superior for producing seed maize with higher germination percentages. Secondary advantages of ear maize drying include the retention of cobs which can be used as fuel and for animal feed. Some (1985) studied various aspects of ambient drying of ear maize as related to storage in freely ventilated cribs. Physical parameters involved in ambient drying of ear maize were reported. While comparing in-bin stirred low-temperature drying with other conventional stationary batch in-bin methods of drying shelled maize, Mwaura (1981) observed that seed drying needs greater control in terms temperature, air flow and drying times during which the seed is subjected to high temperatures. Nellist (1978) quoted different country specifications for conditions of drying seed maize.

Nellist reported that those conditions are very specific and are constantly being reviewed as other techniques of seed maize conditioning are evolved. It is therefore hard to avoid the conclusion that there is lack of precision in the definition of maximum safe drying temperatures. Table 9-3 (Appendix A) also gives some temperature and moisture conditions for drying seeds.

In a research involving drying of three seed maize parents, Navratil et al. (1984) subjected the seed lines to various time-temperature treatments in order to establish heat tolerance levels. It was evident that different maize varieties may have widely varying levels of heat tolerances which can affect their planting value when drying is done outside the prescribed limits.

Many researchers (Giles, 1986; Nellist, 1978 ; Mwaura, 1981 ;Brooker et al, 1982) have indicated the importance of harvesting maize crop once it has reached physiological maturity (normally between 35-40% moisture content, wet basis). Seed maize in such a state of moisture has to be dried down to 14% moisture content before it starts losing its germination ability. High moisture state has also been shown to be critical since there is increased respiration which has the twofold effect of encouraging microbial growth and

heating of the crop (Barre et al. 1988). All these factors have deleterious effect on germination percent and crop vigour.

Considering the increasing work being done to develop new varieties, there is greater need than before to break away from direct application of the popular mono-layer drying theories of shelled maize to ear maize drying. The design of different ear maize drying systems (Appendix C1-C4), has for along time been based on models developed for American dent and flint maize varieties. This has obvious limitations due to the fact that drying parameters are related to material physical configurations of size, shape and other intrinsic vegetal and environmental factors. The American dent-yellow maize definitely has properties that are different from the Kenyan varieties such as the tiny Pwani hybrid, the robust H512 and the long H8103. A seed processor should be able to describe scientifically what happens to the seed at specific points in the conditioning process. Mathematical models are therefore needed for the design, operation and control of local ear maize drying processes.

2.3 Analytical methods of seed quality.

Depending on the different needs of different researchers, other categories have been used. Some of these aspects include the 1000 seed weight, genetic quality, analytical purity and seed health.

The 1000 seed weight or the number of seeds in 1 kg sample is a useful measure of how many seeds can be planted on a given area of land. Farmers would most likely be interested in using the criteria giving the number of seeds per kilogram. Adams et al (1977) indicated that weight loss can occur through damaged grain. The authors proposed a method of weighing and counting damaged and undamaged grains and then relating the two aspects in a defining equation. Factors which are indirectly related to loss such as dust and cob weights in a seed sample may be converted to seed loss by producing a graph from experimental results to be used in sample analysis. The argument here is that the proportion of dust and cobs in a supposedly clean batch of seed constitutes "inert" material which is invaluable to the farmer.

Kelly (1988) also listed other factors like genetic quality, analytical health and physical conditions as quality attributes which are of importance in seed processing. In addition seeds need to have good storage quality to ensure that they

maintain their condition until used for sowing. The moisture content of the seed plays a vital role in maintaining seed keeping quality and so it must be evaluated from time to time. Kelly (1989) emphasized the use of right quality seed by stating that the seed must be healthy, capable of vigorous growth and free from weed seeds. His contention was that no amount of fertilizer, pesticides, fungicides or irrigation water would provide a good crop if the plants growing in the field are not capable of exploiting these inputs to the full.

3.0 THEORETICAL ASPECTS.

In this section, background information is given concerning theories of grain drying, stress cracking and general grain damage during handling operations. Seed quality analysis by using germination models are also reviewed.

3.1 Thin layer drying.

Thin layer drying refers to the drying of grain which is entirely exposed to the air moving through the product (Hall, 1980; Brooker, 1982) . A simplified mathematical model for describing the drying of capillary porous products was developed by Luikov in 1966. The generalized form of this Newtonian diffusion equation is:

$$\frac{\partial M}{\partial t} = D_j \left[\frac{\partial^2 M}{\partial r^2} + \left(\frac{c}{r} \right) \frac{\partial M}{\partial r} \right] \quad (3.1)$$

The following initial and boundary conditions have been used in solving the above equation:

$$\frac{\partial M}{\partial r} = 0, \quad r=0, \quad t \geq 0 \quad (3.2)$$

$$M = M_o, \quad r = R, \quad t > 0 \quad (3.3)$$

$$M = M_o, \quad 0 \leq r \leq R, \quad t > 0 \quad (3.4)$$

where M=moisture content (db) at time t hrs, c is the shape factor, r is the radius of particle and D_j are

diffusion coefficients. The complete analytical solution of this equation can be obtained from Crank (1975). For a spherical body, the following solution apply (Brooker et al. 1982):

$$MR = \frac{6}{\Pi^2} \sum_{n=1}^{\infty} \frac{1}{\Pi^2} \text{Exp}\left[\frac{-n^2\Pi^2}{9} X^2\right] \quad (3.5)$$

The average moisture content and the time are expressed as dimensionless quantities, MR and X, respectively:

$$MR = \frac{M - M_e}{M_o - M_e} \quad (3.6)$$

and

$$X = \frac{A}{V} (Dt)^{\frac{1}{2}} \quad (3.7)$$

where A represents the surface area and V the volume of the body. For a cylinder, the ratio $A/V = 2/r$. The drying parameter k relates the diffusion coefficient and the shape of the material (Steffe et al.1982):

$$k = \frac{X^2}{t} = \left(\frac{A}{V}\right)^2 D \quad (3.8)$$

When equation (3.1) is solved in spherical coordinates, then equation (3.8) reduces to:

$$k = \frac{D n^2 \Pi^2}{R^2} \quad (3.9)$$

This analytical equation was used by Steffe and Singh (1980) who considered rice as a composite sphere of three concentric shells. They designed experiments to determine three parameters one at a time, associated with drying of rough rice. These three parameters were moisture diffusivity of starch endosperm, bran and hull. Similar work carried out by Noomhorm et al. (1986) and Sharma et al. (1982) revealed that two-term models can be used to explain the different drying characteristics of rough rice components. Chhinnan and Young (1977) also considered the peanut pod as a composite spherical body of two differing materials consisting of an inner spherical core of one component (kernel) and an outer concentric shell of another component (hull). Using a non-linear optimization technique with a search programme, Bakshi and Chhinnan (1984) estimated moisture transport parameters in various food components by a similar method.

3.2 Drying parameters.

The diffusion coefficient, D , is a rate term expressing the volume in cubic metres of moisture transferred per square metre of cross-section per metre thickness per hour. It does not include the vapour

pressure driving potential of the drying process which is represented by $(P_v - P_{v\infty})$ or $(M - M_c)$, (Hall, 1980; Barre, et al. 1988). As stated by Brooker, et al. (1982), diffusion coefficients or drying constants are only applicable to specified temperature and moisture content ranges. Chu and Hustrulid (1968) used Arrhenius-type equations to express the relationship between the diffusion coefficient, moisture content and temperature of the maize kernels in the 120°F to 160°F temperature range and the 25 to 36% (wb) initial moisture content range. One such equation obtained is of the following form:

$$D_{\text{corn}} = 1.2 \times 10^{-3} \text{ Exp} \left[(2.5 \times 10^{-4} \theta + 0.107) 100M + \frac{444}{(\theta + 524)} \right] \quad (10)$$

where θ is temperature in °R and M is moisture content (db). Different k or D values would be obtained for the various rate periods if they were discernible. The k -value is proportional to air flow rate, Q_a , specific heat, c , and the water vapour pressure at saturation, p_s . The rate of drying dM/dt , which is equal to the vapour pressure driving force divided by the resistance to drying is given as:

$$\frac{dM}{dt} = \frac{(p_g - p_a)}{\frac{1}{k_g a_m}} = k_g a_m (p_g - p_a) \quad (3.11)$$

where

M = mean moisture content, kg water/kg dry grain;

k_g = mass transfer coefficient, kg water/s m²;

a_m = effective area, m² ;

p_g = vapour pressure of grain, N/m²

p_a = vapour pressure of air, N/m².

The driving force of moisture movement is given as ($p_g - p_a$) and the resistance to drying is $1/k_g a_m$ (Hall, 1980).

3.3 Application of drying models.

Diffusion-based models have become more popular since they provide a conceptual basis for physically understanding the drying process. As a result of their development, Newton's law of cooling-type equations have formed the background to these diffusion-type models (Barre 1988). A single term model of equation (3.5) has the form shown below:

$$MR = \frac{M - M_e}{M_o - M_e} = \text{Exp}(-kt) \quad (3.12)$$

Generally this single term in equation (3.12) above can be obtained by integrating an equation developed by assuming that the rate of moisture removal is

proportional to the difference between the product moisture and its equilibrium moisture content:

$$\frac{dM}{dt} = -k(M-M_e) \quad (3.13)$$

White et al. (1980) used this type of equation to describe the drying behaviour of fully exposed popcorn. Syarif et al (1984) referred to a modification of the above equation developed by Page in 1949. This Page equation is of the form:

$$MR = \text{Exp}(-kt^N) \quad (3.14)$$

where N is a decimal exponent.

Most drying models have been modifications of Thomson's thin-layer equation where time is regarded as the dependent term (equation 3.15). In this Thomson's model, A and B are coefficients which vary with the drying air temperature.

$$t = A \ln(MR) + B [\ln(MR)]^2 \quad (3.15)$$

Chhinnan (1984) cited a two-term semi-empirical model developed by Glenn in 1978 to describe thin-layer drying of maize kernels. He represented the kernels as two discrete lumps with moisture ratio as the dependent variable:

$$MR = A_0 e^{-k_0 t} + A_1 e^{-k_1 t} \quad (3.16)$$

Sharaf-Eldeen et al. (1980) used a similar expression in equation (3.17) and found that two terms were adequate for describing ear maize drying.

$$MR = \frac{M - M_e}{M_0 - M_e} = A e^{(-k_d t)} + (1-A) e^{(-Bk_d t)} \quad (3.17)$$

where A,B = dimensional characteristic constants for ear maize.

k_d = a parameter which depends on air temperature and kernel initial moisture content.

More accurate work has revealed that during the falling rate period, the material can exhibit even more than two falling rate periods depending on the mode of mass transfer, which to a large extent is governed by the discrete components of the biological material (Kumar et al. 1982). Ear maize is one such material which has two easily identifiable cob and kernel components. The pith forming the central portion of the cob is yet another region that creates an additional interface.

Ear maize drying at Seed Driers Limited takes place according to the process illustrated in Appendix C3. This is a two pass system where cooler and moisture-laden air from drier bins is made to pass through a bin of wetter ears. A slight modification of equations (3.16) and (3.17) was used to model this two-phase mode of drying, since the first stage of drying can generally be described with a single term equation. This general model when given as a step function has the following form:

$$\begin{aligned} MR &= \text{Exp}(-k_1 t) && \text{for } t < t_0 \\ MR &= A [\text{Exp}(-k_2 t)] + B [\text{Exp}(-k_3 t)] && \text{for } t > t_0 \end{aligned} \quad (3.18)$$

where t_0 is the time to the change of drying mode (i.e. change of air flow direction and temperature).

3.4 Stress Cracking.

The goal of studies on stress cracking is the development of criteria for selecting drying conditions which avoid stress cracks. A theoretical background for such criteria is desirable since it is likely to extend the applicability of experimental results. Misra et al. (1981) recognised the difficulty involved in measuring stresses in cereal grains in order to verify theoretical solutions by developing finite element procedures for predicting shrinkage techniques, due to moisture gradients alone, and to compare the maximum predicted stresses for various drying conditions to the number of cracks observed for those conditions. Gustafson, et al. (1979) derived relations for calculating shrinkage stresses experienced when near-spherical biological materials dry using stress-strain relationships for a sphere and assuming a Hookeian solid. Friedley et al. (1968) and Miles et al. (1973) found that shear stress is the most significant parameter for failure in biological products even though numerical values of tangential and radial stresses will be greater. The authors gave the following relationship for calculating the maximum shear stress at any point in a sphere from the radial and tangential stresses:

$$\tau_{\max} = \frac{1}{2} \text{ABS}(\sigma_r - \sigma_t) \quad (3.19)$$

where τ_{\max} = maximum shear stress at any point
in a sphere, Pa.

σ_r = radial stress at the point, Pa.

σ_t = tangential stress at the point, Pa.

Misra and Young (1980a) assumed that these materials are elastic and found that the modulus of elasticity E , varies during drying and is a function of average moisture content, M (% wet basis). They obtained a relationship for modelling soybean shrinkage as follows:

$$\log_e(E) = 20.12 - 0.55 [\log_e(M) - 0.87]^2 \quad (3.20)$$

3.5 Seed Germination Models.

For many years the percentage germination obtained at an intermediate stage in the standard germination test was taken as an indication of the potential field performance of the seed (Bould, 1981). This concept has, however met with vigorous attack mainly on the basis of problems arising out of standardisation and interpretation of results. In order to characterize the germination pattern precisely, Heydecker (1966) indicated that final percentage germination, time to 50% germination and the variance of the number of seeds germinating in successive time intervals is required.

Regarding a batch of seeds as if it were an organic whole obscures the fact that the batch is made up of individuals and it is each one of these that is more or less vigorous.

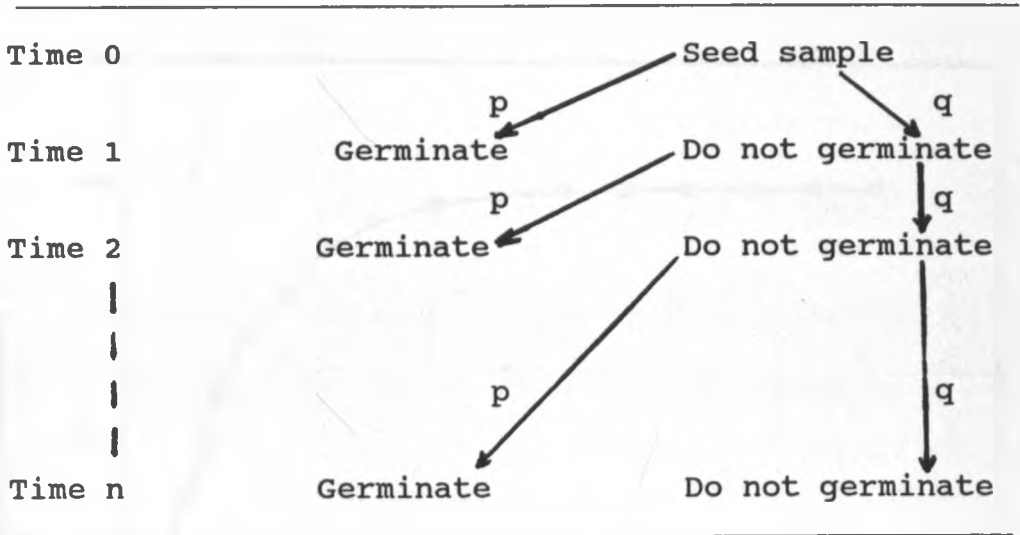
Starting with biological models, mathematical formulae have been developed to describe the resulting pattern. A seed sample may consist of one or more sub-groups in which the probability of a seed germinating in unit time is constant within a sub-group. The probability of a seed germinating in unit time allows the presence of seeds with different rates of germination to be defined in a mathematically tractable way.

Two general solutions arise:

1) Each seed in the sample has the same probability of germinating in unit time. This does not imply that all the seeds germinate at the same time.

If p is the probability a seed germinating in unit time and $q=1-p$ with $0 < p < 1$, then the situation can be represented diagrammatically as shown in Table 3-1.

Table: 3-1 Seed germination model development.



(Source: Bould et al, 1981)

The proportion of seeds germinating after each time interval with the time measured from the time of the first seed to germinate, is given by:

Time units	0	1	2	3	4	t
Proportion germinating	0	p	pq	pq ²	pq ³	...	pq ^(t-1)

If A seeds are viable, the number of seeds germinating (G) after a given number of time units (t) is:

$$G = A (1 - e^{-kt}) \tag{3.21}$$

where $-k = \log_e q$.

Since $dG/dt = kAe^{-kt} > 0$ for all $t > 0$ and

$d^2G/dt^2 = -k^2 Ae^{-kt} < 0$ for all $t > 0$, the graph of the curve is increasing and has no point of inflection (Figure 3.5).

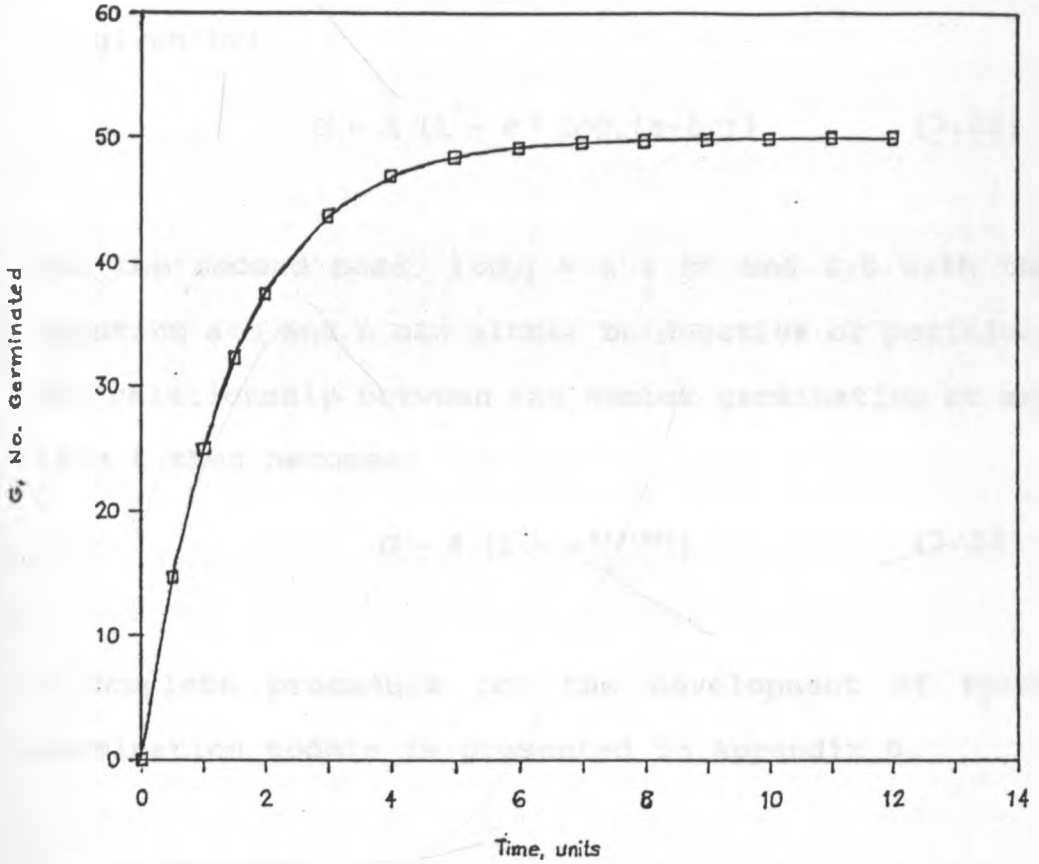


Figure 3.5 An example seed growth curve.

2. The seed sample contains sub-groups. The probability of a seed germinating in unit time is constant within a sub-group but varies between sub-groups.

There are two possibilities of having linear equations between (1) q and t and (2) $\log_e q$ and t .

In the first case, $t > 0$ and $q = a + bt$ where a and b are constants at any time t , the number of seeds germinated is given by:

$$G = A [1 - e^{-t \log_e(a+bt)}] \quad (3.22)$$

For the second case, $\log_e q = a + bt$ and $t > 0$ with the constant $a < 0$ and b can either be negative or positive. The relationship between the number germinating at any time t then becomes:

$$G = A [1 - e^{-t(a+bt)}] \quad (3.23)$$

A complete procedure for the development of these germination models is presented in Appendix B.

3.6 Viability models.

The percentage viability, which is the percentage of grain which germinates in the International Seed Testing Association test (ISTA, 1985), is a useful measure of the harshness of drying and storage conditions and has been used as such in standard grain drier procedures (Bowden, et al. 1983). The frequency of individual deaths in time in a grain sample under constant environmental conditions can be described by the normal distribution (Roberts, 1972).

$$y = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(t_v - t_0)^2}{2\sigma^2}} \quad (3.24)$$

where y is the relative frequency of deaths occurring at time t_v and σ is function dependent on the moisture content and temperature of grain. Equation (3.24) can be transformed so as to plot as straight lines on linear scales (relative frequency of deaths then becomes the probit viability) and this gives the following Roberts-Nellist viability model.

$$v = K_i - p\left(\frac{1}{\sigma}\right) \quad (3.25)$$

where v is the probit viability at any time and K_i is v at the beginning of drying. Nellist (1981) adapted equation (3.25) for use in conditions where both temperature and moisture content are constantly changing with σ being given as:

$$\log_{10}\sigma = K_E - C_w \log_{10}m - C_H t - C_Q t^2 \quad (3.26)$$

where K_E , C_w , C_H and C_Q are seed viability constants which are specific for each crop.

From equation 3.25, the change in viability, δv_j , in any layer j of grain at any time t_v is given by (Bowden, 1983):

$$\delta v_j = -\left(\frac{1}{\sigma_j}\right) \delta t_v \quad (3.27)$$

For these equations to be applicable, heat and mass transfer equations must be solved for every layer of grain or ears. Enormous computer times would be required to achieve this task. The constants cited in equation 3.26 must be obtained for the particular grain being considered. International Board Plant Genetic Resources (1985) came up with a simplified solution to this problem which might be applicable for gene banks. The loss in probit viability occurring during the period of drying was represented by K_1-v . There is need to determine the constants cited in equation 3.26 for seed maize varieties, especially the ones that tend to deteriorate faster in germination due to drying or storage.

4.0 METHODOLOGY.

This chapter provides the details of data collection, their possible limitations and the analysis. Two categories of data are included here. The primary data mainly from drying experiments carried out to determine the drying parameters for the two stage in-bin drying of ears at the Seed Driers Limited (SDL), the determination of unit capacities, efficiencies and the various laboratory experiments for germination and other seed quality analyses like mechanical damage. The secondary data were obtained from the records maintained by the SDL on the various factors used for determination of clean seed output.

4.1 Instrumentation.

In this section the various instruments and equipments that were used for data collection and analysis are briefly presented. The shortcomings encountered when using the instruments are also discussed. Generally it was observed that for drying experiments to be meaningful the method and precision in data acquisition has to be verified accurately. These are conditions that are not always adhered to in field experimentation, especially for experiments that do not require interruptions in the sequence.

4.1.1 Moisture content determination.

The methods for determining the moisture content of products may be divided into two broad categories (Hall, 1980). These are (1) direct and (2) indirect methods. The use of air-oven is the most common direct method of moisture determination. In this work, a temperature of 130°C is maintained on whole grain samples for 16 hours. When ground samples are used, a temperature of 103°C is maintained for a period of 4 hours (ASAE, 1987). Indirect methods involve measuring a property of the material which is related to its moisture content such as resistance, capacitance or thermal conductivity. These indirect methods are quicker, but less accurate. The standard oven method was therefore used to calibrate the capacitance-type meter used for evaluating the moisture contents. A Super-matic moisture tester similar to the Steinlite meter described by Hall (1980) was used. The procedure involves placing a 230g sample of shelled maize in a chamber consisting of capacitance plates. The reading is then obtained automatically by a light indicator on the instrument body. The meter itself has an accuracy of 0.5 for the moisture contents encountered with the grains studied. The equipment is provided with different plates calibrated for use with different grains. Table 4-1 and Figure 4.1 shows, respectively,

moisture content data and the calibration curve obtained for the Super-matic moisture tester against the standard air-oven method.

Table 4-1 Moisture content data for meter calibration

Cap. Method	Oven Method	Fitted data
11.7	10.16	9.960
11.8	10.26	10.014
12.0	10.28	10.123
12.5	10.41	10.402
12.7	11.08	10.516
12.8	11.26	10.573
13.9	11.50	11.225
14.5	11.81	11.597
15.4	11.56	12.178
15.6	11.62	12.311
16.6	12.59	12.999
16.9	12.74	13.213
19.6	13.92	15.301
20.5	13.99	16.068
24.3	22.04	19.755
25.0	22.32	20.521

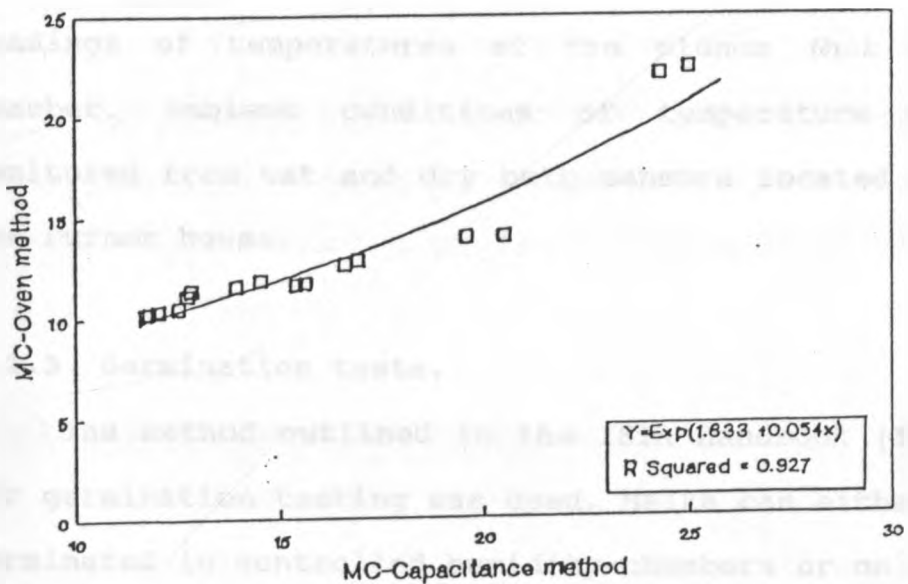


Figure 4.1 Moisture meter calibration curve

4.1.2 Temperature measurements.

Temperatures within the bins were measured using copper-constantan thermocouples connected to a Proccos MP-110 digital data logger (Plate 9.1). The equipment, accurate to 0.1 of a degree, gives readings directly in degrees Celsius. In each bin, two sensing points were placed at the top of the drying ears as well as the bottom. The two sensing points in each location were used to measure the wet and dry bulb temperatures. This helps to indicate the extent to which the hot air is being utilized. A narrow difference between the inlet and outlet dry bulb temperatures would imply that maize is almost dry. The wet bulb readings were obtained by covering the thermocouple junctions with a wick dipped in water on plastic containers (Plate 9.13).

A thermohydrograph was also used to give charted readings of temperatures at the plenum (hot air) chamber. Ambient conditions of temperature were monitored from wet and dry bulb sensors located near the burner house.

4.1.3 Germination tests.

The method outlined in the ISTA Handbook (1985) for germination testing was used. Maize can either be germinated in controlled humidity chambers or on sand substrate. The latter procedure was followed in this

work since it is cheaper and has less complexities. The sand used was first sieved and then washed with hot water to kill any undesirable organisms. The other purpose of washing is to remove any nutrients from the sand. At Kabete the germination tests were similarly run in a glass house using sand as substrate.

4.1.4 Damage analysis.

The percent of damaged seed was evaluated by screening 500g samples using No. 20R screen. The seeds were then stained with Fast Green dye and the number of seeds damaged obtained. Incidence of internal damage were investigated using an X-ray machine available at the Department of Clinical Studies in the Faculty of Veterinary Medicine of the University of Nairobi. It was difficult to obtain good resolutions even after trying several times. The method of taking counts for cracked or chipped grains was then adopted in analysing the level of damage caused by sheller. This type of damage could easily be isolated because it is mainly the sheller that produced a lot of cracked seeds.

4.2 Sampling.

The relevance and applicability of results of quality analysis in a seed industry to a large extent depends on the method of sampling. The selection of

appropriate sampling method must consider the type of material being sampled, the level of accuracy desired and the expected use of the results. Sampling when carried out poorly only leads to a waste of resources which could be utilized elsewhere. However good the analysis of the results obtained from such sampling might be, their implementation is bound to be misleading and less practical.

4.2.1 Field sampling .

From the time maize seed is ready for harvesting in the field, several random samples are necessary for the determination of quality and any unusual attack by insects or diseases. This information is necessary so as to help in planning subsequent handling and processing operations. Processing of seed is not intended to turn bad seed into good seed, but rather it is meant to remove the undesirable components such as other weed seeds, stalks, cobs, rotten ears and any soil particles. A seed lot free of these foreign bodies is better suited in meeting the standards set by the International Seed Testing Association (ISTA) and the National Seed Quality Control Service (NSQCS). Sampling before seed is harvested from the field also has the additional objective of determining the maturity of the crop. The farmers together with the field supervisors

use either the portable moisture meters¹ or visually check the "black spot" maturity index on the kernel where it gets attached to the cob. With experience the latter method is the easiest for establishing the physiological maturity of the maize when germination percentage and dry matter content is maximum.

Seed maize harvested when the kernel moisture content is more than 30% (wb) has the tendency to deteriorate faster and so the processing should begin not more 24 hours after harvesting. The handling of seed in such a wet state causes increased damage when loading onto and from trucks (Plate 9.3). So at earlier stages of the harvesting season, seed lots from the field should be sampled to ascertain the degree of such handling damage. Visual inspection and sampling for the determination of initial moisture content as the seed arrives at the plant is also necessary. This latter aspect is carried out at the Seed Driers Limited to establish the general state of moisture as the crop is received.

4.2.2 Pre-conditioning sampling.

As the seed arrives at the Seed Driers Limited, visual inspection and sampling for the determination of initial moisture content is done. Culling of rotten ears and proper de-husking is done by the farmers in

the field. Once the seed is received, between seven to eight lorry loads of wet ears weighing approximately eight tonnes are emptied into a single drying bin. A one bag sample from each lorry must be taken to help determine the selection factor, drying factor and the shelling efficiency. The selection factor is determined by removing chaff, rotten ears, off-type ears and other inert material from the one bag sample obtained randomly from each lorry at reception. The drying factor gives the amount of moisture removed per kilogram of clean selected ears. A composite sample is then taken by mixing the seven or so bags in order to determine the bin adjustment factor since the lorries normally deliver seed from different farmers. The bin adjustment factor is gives the overall composition of the ears in terms of moisture state and level of cleanliness of all lorry loads received from various farmers. The use of these factors mainly help in indicating the amount of down-payment to be made to farmers before processing of the delivered seed is completed.

4.2.3 Bin sampling.

The maize seed that is loaded in drying bins should be free from excessive husks, sticks and any other stray varieties (called off types). Taking of

samples from the bin is mainly for the purpose of monitoring the progress of drying. Samples have to be taken from top and bottom of the drier in order to determine the moisture state of the maize as it dries. Hot air cannot be released directly onto very wet maize seed and so pre-conditioning drying has to be carried out as reported by Herter et al.(1989) . The major reason is that wet maize is more susceptible to drying injury than relatively dry maize. The two metre bed depths used for ear maize drying also necessitate the changing of the drying mode and this therefore calls for proper sampling for moisture content determination. Lowering of germination percent can easily result if controlled sampling is not done. The moisture content within which this lowering of germination takes place is the uncertain factor in Kenyan maize seed varieties. Once the maize has dried to a certain moisture state which is usually fixed by the state of drying in other bins, the direction of air flow is changed to allow hotter air to dry the maize down to 14% (wb). At the end of the drying process, maize ears at the top of the bin are normally drier than the ones at the bottom since hot air used for drying enters at the top and exits at the bottom of the bin. This mode of drying may affect germination of the maize at the top since they are exposed to hotter air than bottom samples, even

though exposure times may be uniform. This is the major reason why samples were both put at the bottom of the bin and at the top of the ears in the bin.

4.2.4 Sheller sampling.

Before shelled maize is delivered for processing, a pre-delivery sample is taken to determine the level of cracked or chipped kernels. Many factors contribute to this mechanical damage. The sheller speed in revolutions per minute (RPM), cylinder clearance, feed rate and other intrinsic ear characteristics such as size and moisture content are the main damage determinants in this pre-conditioning process. The shelling characteristics of a given variety reveal a lot about its perceived physical attributes like kernel strength and other textural aspects. The interaction between machine parameters or settings and these physical aspects may also be crucial in fixing the product quality.

About 2 kg samples were taken from the shelling unit immediately the timed grains left the pre-cleaner. The average time from shelling, elevation through bucket elevators to pre-cleaning was noted so as to achieve near representative sampling. The variation in sheller speed, in revolutions per minute, was measured using a hand-held digital tachometer. Since the grain

goes through an elevator and the pre-cleaner after being shelled, it was necessary to determine the time lapse between shelling and sampling. This ensured that the right sample shelled at a given speed was taken.

4.2.5 Processing plant sampling.

The main conditioning and upgrading of seed quality takes place at the processing plant where the following major operations are involved: (1) Cleaning, (2) Sizing or grading, (3) Chemical treatment or dressing, (4) Weighing and bagging. Sampling at this stage is carried out to determine the extent to which the first two unit operations of cleaning and sizing have been carried out. This then helps to determine the efficiencies of the two processes. The points from which samples were taken are shown in the flow diagram indicating the processing channels (Figure 4.2). The bar chart in figure 5.6 shows the quality enhancement in terms of chipped grain and materials other than clean seed occurring in the sample as the maize moves through the screen arrangements .

4.2.5.1 Actual seed in screenings.

Kenya Seed Company has two seed maize processing factories located in different places. One is at Seed Driers Limited (Endebbes) while the other is at Kenya

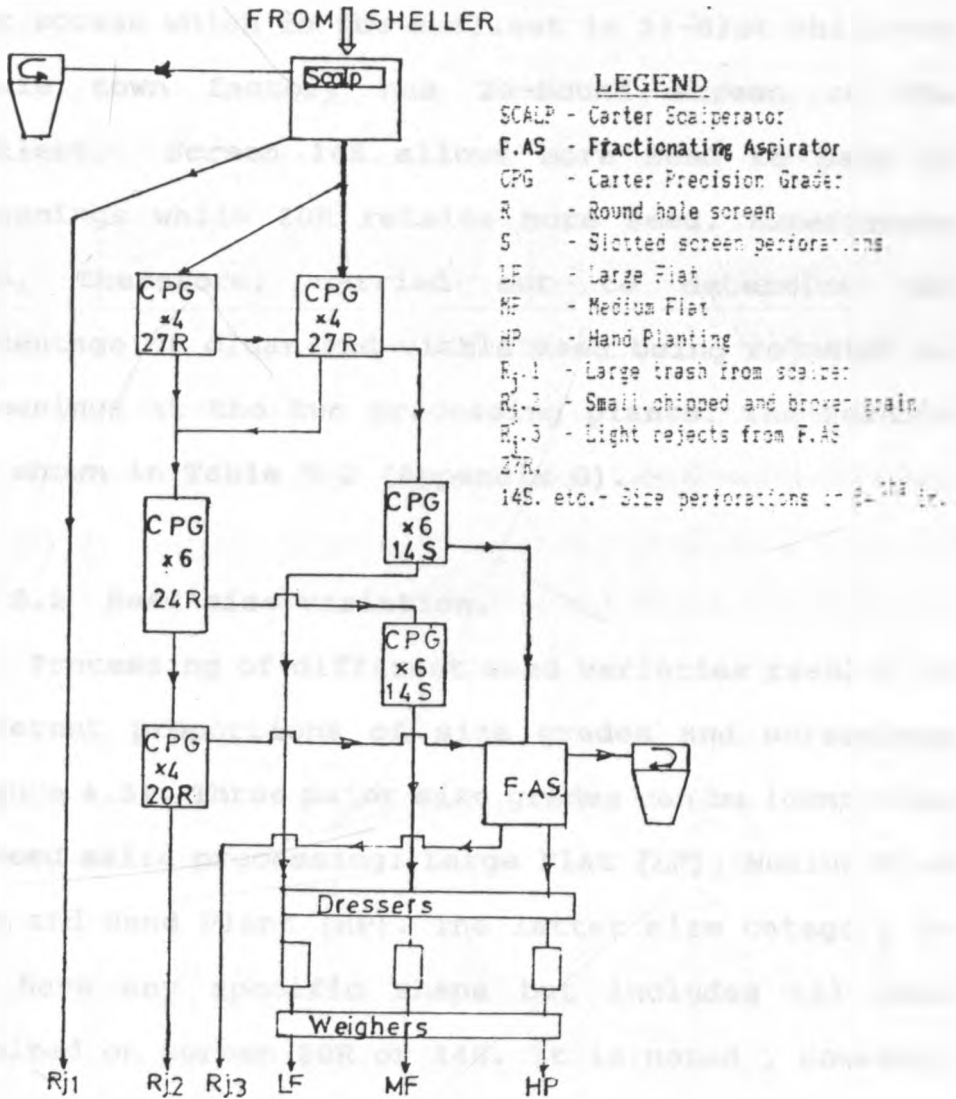


Figure 4.2 Seed maize processing plant flow diagram

Seed Company -Kitale. These plants operate on different sets of screen arrangements (Mwangi, 1990). At SDL the last screen which is the smallest is 14-Slot while the Kitale town factory has 20-Round screen as the smallest. Screen 14S allows more seed to pass as screenings while 20R retains more seed. Experiments were, therefore, carried out to determine the percentage of clean and viable seed being rejected as screenings at the two processing plants. The results are shown in Table 9-2 (Appendix G).

4.2.5.2 Seed size variation.

Processing of different seed varieties results in different proportions of size grades and screenings (Figure 4.5). Three major size grades can be identified in seed maize processing: Large Flat (LF), Medium Flat (MF) and Hand Plant (HP). The latter size category do not have any specific shape but includes all seed retained on screen 20R or 14S. It is noted, however, that the proportions of the size groups processed depends mainly on the market demand.

4.3 Drying experiments.

Various treatments were given to maize varieties to determine temperature-time effects on vigour ratings such as Mean Germination Time (MGT), Viability Index

(VI) and percent of germinated seed (PGS). A laboratory drier (Plate 9.6), a forced convection oven and 64-ton capacity ear maize drying bins (Plate 9.9) were used for drying the samples. The procedures followed in the experimentation are reported in the sections that follow.

4.3.1 Oven drying experiments.

Different temperature settings in the range of 40°C to 70°C were used. The samples were withdrawn at different stages from the oven to give a series of temperature-time treatments. The grains from the ears given the different treatments were then laboratory tested for germination. Daily counts, 4-day and 7-day counts were used for analyzing the samples.

Due to instances of improper burner control, plenum temperatures can overshoot to 50°C or above. The effect of such an occurrence on germination was investigated by drying samples of H614 maize variety in a forced convection oven at the ADC Feed Mill laboratories. These samples were similarly tested for germination at the KSC quality control laboratory.

The relationship between moisture contents of shelled maize, ear maize and cobs was also established by drying them concurrently in the oven set at 42°C. Final moisture contents when drying stopped were

determined by the oven air set at 130°C for 16 hours. Calibration experiments for the capacitance moisture meter were also carried out in the oven under similar conditions.

4.3.2 Laboratory drier-Kabete.

Samples of Katumani composite and H511 were dried under controlled conditions using an existing laboratory drier which was modified to achieve controlled temperatures in the range of 30-60°C commonly used in drying ear maize for seed. Four stacks of trays filled with wet ears were dried until equilibrium conditions were attained; that is, when the weights of trays were no longer changing. The samples were placed in onion nets and drying progress monitored by recording the change in weights. The samples were placed at different depths (i.e. from the bottom tray to top tray) to approximate the drying system at SDL. Copper-constantan thermocouples were placed at the plenum chamber, on four trays 1-4 as shown in Plate 9.6 with tray 1 being closest to the plenum while tray 4 was the top-most). One sensing point was for measuring the ambient conditions. Cob temperatures were also monitored throughout the drying process. Data obtained from these tests were used to establish the drying parameters k and M_c and the germination rates.

Germination tests were carried out inside a plant-house at the University of Nairobi Field Station at Kabete. The ISTA procedure for germination testing was used for analyzing the results. Four 25 seed replicates were used to determine the germination capacity. Counts were made from the time first shoots pierced the levelled surface of sand substrate up to the seventh day when the last count was made.

Renhard (1988) defined Mean Germination Time (MGT) by the following expression:

$$MGT = \frac{\sum n_i j_i}{\sum n_i} \quad (4.1)$$

where j_i is the number of seeds germinated on day n_i . For fast germinating seeds, n_i can also be measured in units of time in hours.

The Vigour Index (VI) is also a rate parameter and is given by the following relationship developed by Maguire (1962):

$$VI = \frac{s_1}{n_1} + \frac{s_2}{n_2} + \frac{s_3}{n_3} + \dots + \frac{s_n}{n_n} \quad (4.2)$$

$$= \sum_{n=1}^{\infty} \frac{s_n}{n_n} \quad (4.3)$$

where s_n is the number of seeds germinated on day n_n

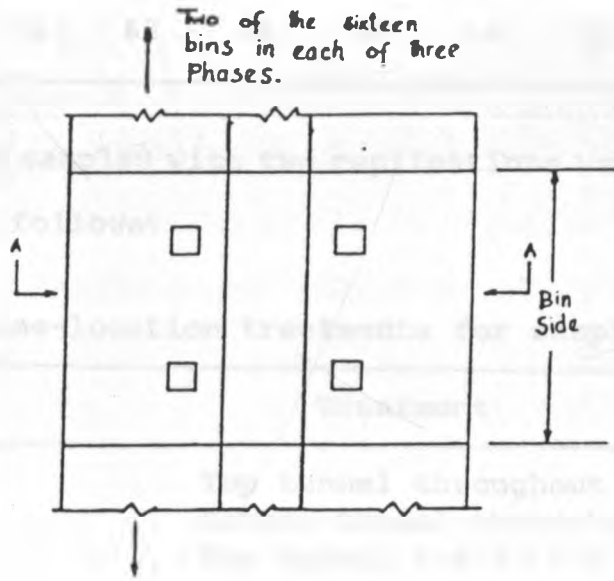
Mean Germination Time (MGT), the Vigour Index (VI) and the final germination percent as defined above were used as indices of planting value of the seeds.

4.3.3 In-bin drying samples

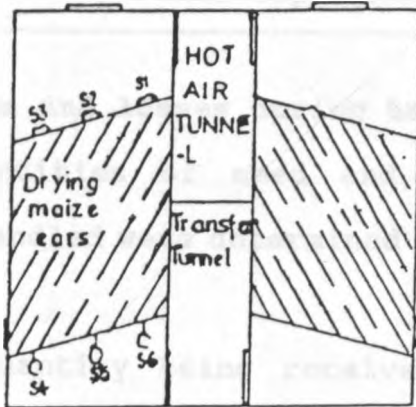
Onion nets which cause minimal restriction to air flow through samples were used for the in-bin drying experiments. Two sets of experiments were carried out. The first involved placing three bag samples of wet ear maize weighing about 5-6 kg at the top and bottom of the bin as illustrated in figure 4.3. The samples were marked S1 to S6.

The next set of bin drying experiments involved placing samples in the tunnels for different periods of time ranging from 0 to 72 hours. Other samples were dried until equilibrium conditions were reached (i.e. negligible changes in weight observed.). Final moisture

contents were determined before carrying out germination tests. The layout for experimentation was set out as presented in Table 4-7.



PLAN VIEW



SECTION A-A

Figure 4.3 Placement of samples in the bin.

Table 4-7: Time period (hrs) taken by samples in top and bottom tunnels.

Sample	A	B	C	D	E	F	G
Bottom (hr)	0	12	24	36	48	60	72
Top (hr)	72	60	48	36	24	12	0

Other four samples with two replications were given treatments as follows:

Table 4-8 Time-location treatments for samples.

Sample	Treatment
I	Top tunnel throughout
II	Bottom tunnel throughout
III	Top tunnel for 36 hrs then bottom tunnel for 36 hours
IV	Bottom tunnel for 36 hours then top tunnel for 36 hours

4.4 Capacities and losses during handling.

Actual quantities of seed and other non-seed material being handled were determined at the following points.

- a) Total quantity being received when wet for each bin. Data were recorded at the weigh bridge.
- b) Total quantity of clean wet ears being loaded into the bin for drying. The weights of rejects were measured to arrive at this figure.

c) Total amount of shelled maize after being dried and the total amount of dry ears. All the cobs were dried to arrive at the weight of dry grains.

d) The total amount of clean seed and the percentage of LF, MF and HP.

These data enabled the various factors for pre-cleaning (or selection), drying, shelling and cleaning to be established. Effectiveness in bin utilization was also established by taking a summary of monthly intake of seed.

4.5 Analysis of data.

In this section, the techniques used in the analysis of data collected are presented. The method of successive residuals is used to evaluate the drying parameters k and M_c for the drying curves. Damage analysis was carried out visually using the fast green die and the germination tests.

4.5.1 Method of successive residuals.

Drying curves normally plot exponentially as moisture content drops with time. The linearisation of dimensional parameters of MR and X is needed in order to obtain a best fit curve. This technique is outlined by Mohsenin (1986) to establish the stress relaxation

parameters for various plant and animal materials (e.g. bovine muscles and fruit skins). It is a statistical technique that considers a decay curve as series of small lines and so the general equation can be presented in the form of a Fourier series. The number of terms of such an equation depends on the drying behaviour of the product. Rudra (1987) used a similar curve fitting procedure to stress relaxation data by writing a computer program in FORTRAN which could generate the coefficients in the multi-term exponential stress relaxation equation of the form shown below:

$$\sigma = \sigma_1 + \sigma_2 + \sigma_3 + \dots + \sigma_e \quad (4.4)$$

In a general form, this equation can be expressed as:

$$\sigma(t) = \sigma_e + \sum \sigma_n e^{(-\frac{t}{\tau_n})} \quad (4.5)$$

σ_e = stress at infinite time in N/m².

n = 1 to ∞

The change in moisture ratio is generally represented by an exponential decay equation as shown below:

$$MR = \sum A_i \text{Exp}(-k_i t) \quad (4.6)$$

t = time, hrs

A_i = dimensionless constants, and

k_1 is a drying rate parameter.

and this equation is analogous to the relaxation model in equation (4.5). The steps given in the Appendix D explain this procedure in detail.

4.5.2 Germination rates.

Four criteria have been used to analyse the germination data. These methods are:

- i) Percentage of Germinated Seeds (PGS).
- ii) Mean Germination Time (MGT).
- iii) Vigour Index (VI), and
- iv) Growth curves.

The PGS is calculated after the 7-day count. Four replications of 50 seeds each are used. For example, if the counts in each of the four replications are represented by a_1 , a_2 , a_3 and a_4 , then:

$$PGS = \frac{1}{4} \left(\frac{a_1}{50} + \frac{a_2}{50} + \frac{a_3}{50} + \frac{a_4}{50} \right) * 100\% \quad (4.7)$$

The use of the Mean Germination Time and the Vigour Index have been explained in Section 4.3.2 Growth curves are generally sigmoid in shape and so exponential equations were fitted to the data so as

have a mathematical description. Two equations of the form shown below are used for analysis.

$$\ln \left(\frac{50}{\text{no. germinated after time } t} \right) = \text{Exp} \left(M_0 + \frac{t}{N_0} \right) \quad (4.8)$$

This equation can also be expressed as:

$$Y = \text{Exp} \left(M_0 + \frac{t}{N_0} \right) \quad (4.9)$$

The natural logarithm of Y (abbreviated GI) is plotted against time t in hours, that is:

$$GI = \ln Y = M_0 + \frac{t}{N_0} \quad (4.10)$$

M_0 and N_0 are constants describing the rate of growth. The other model that has been used is a plot of the logarithm of $(\text{PGS})^{-1}$ against t^{-1} .

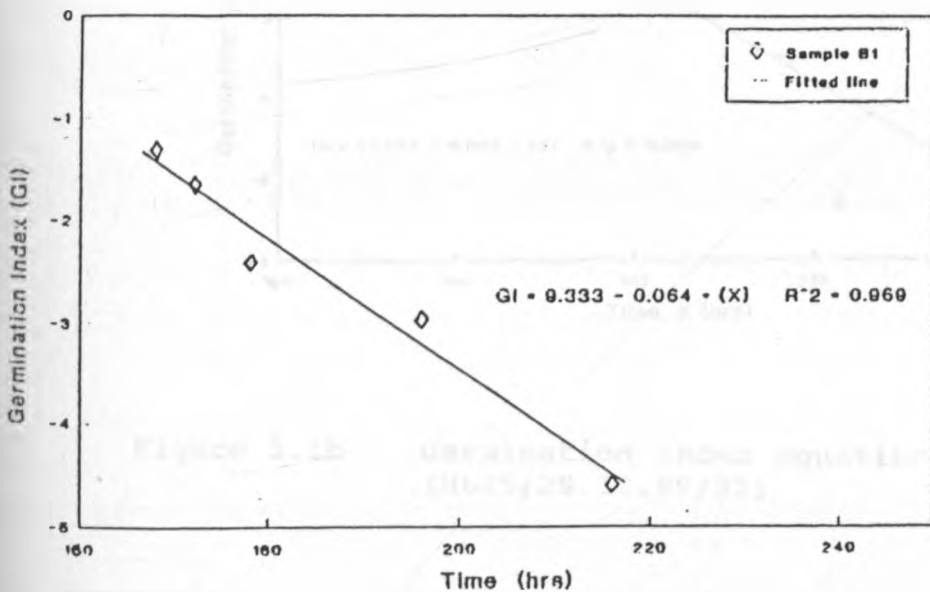


Figure 5.1a Germination Index equation for sample B1 (H625/29.12.89/23)

5.0 RESULTS AND DISCUSSIONS

5.1 Effect of drying on germination.

Germination curves for varieties H8103 and H625 are given from the observed data. The model, $\log(\text{PGS})^{-1}$ against the inverse of time from start of germination has been used. All the r^2 are between 0.85 to 0.98 for both varieties. The Germination index (GI) as used for describing growth curves for H625 also gave values of r^2 ranging from 0.710 to 0.997 for bin 29.12.89/23.

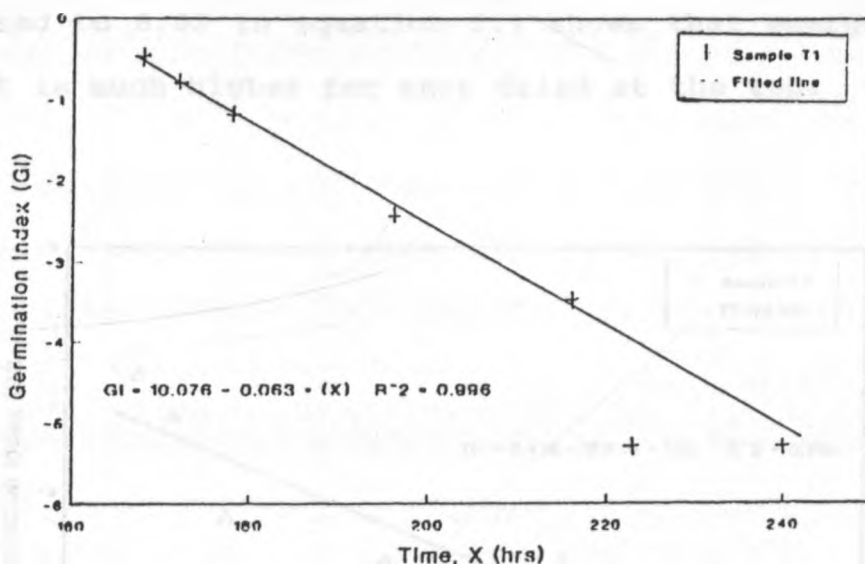


Figure 5.1b Germination Index equation for sample B3 (H625/29.12.89/23)

The generalized equation obtained for all samples dried at the bottom of the bin is:

$$GI = 6.02 - \frac{1}{24} \cdot t \quad (5.1)$$

and for samples dried at the top,

$$GI = 8.73 - \frac{1}{17} \cdot t \quad (5.2)$$

The gradient of the GI versus time curve for samples dried at the top of the bin has a larger absolute value and this indicates higher growth rates. The higher value of the constant 8.73, in equation 5.2, as opposed to 6.02 in equation 5.1 shows that emergence count is much higher for ears dried at the top.

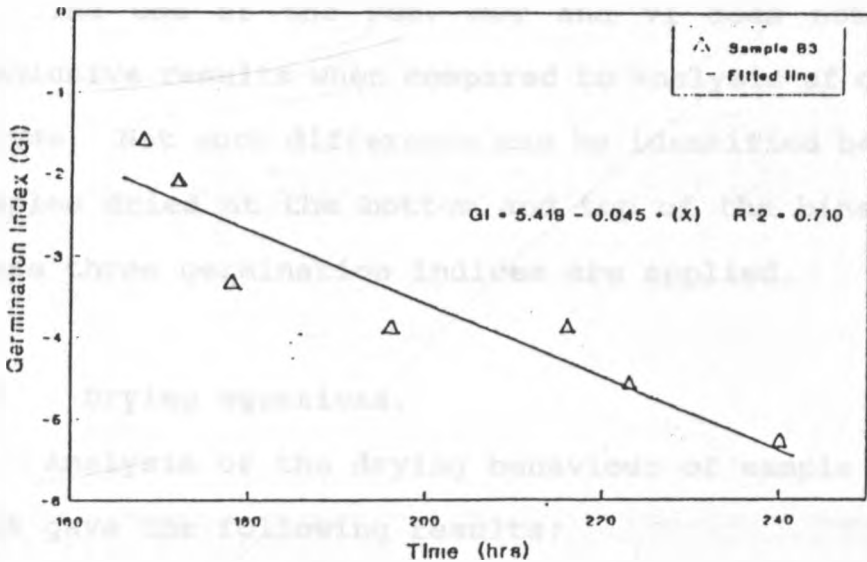


Figure 5.1c Germination Index equation for sample T1 (H625/29.12.89/23)

Statistical analysis using a paired t-test for analysing the difference between two treatments (top and bottom samples in this instance), is presented in Appendix G for seed maize varieties H8103 and H625. The analysis is done for two bins of H625 and one for H8103. The null hypothesis considered in all the two cases is that there is no difference in germination rate between the two treatment locations ($\mu_0 = 0$). H625 resulted in highly significant values of calculated t-statistic. H8103 gives a non-significant result, but the confidence interval (CI) at the 95% level is positively skew, indicating that the probability of rejecting the null hypothesis is higher. This interval lies between -0.668 to 5.268.

The use of the PGS, MGT and VI does not give conclusive results when compared to analysis of growth curves. Not much difference can be identified between samples dried at the bottom and top of the bins when these three germination indices are applied.

5.2 Drying equations.

Analysis of the drying behaviour of sample BB of H625 gave the following results:

1st stage drying:

$$MR = 0.98 e^{-\frac{1}{92}t} \quad (5.3)$$

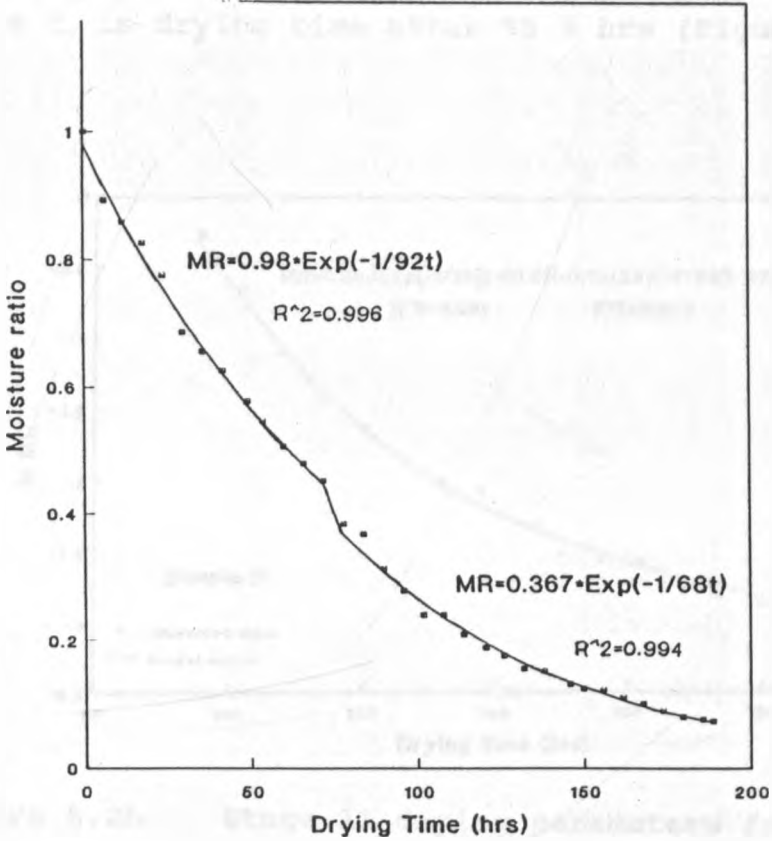


Figure 5.2a Drying curve for H625 sample BB/bin 23

2nd stage drying.

$$MR = 0.367 e^{-\frac{1}{68}t} \quad (5.4)$$

Second stage drying of the same variety for a sample placed at the top of the bin during drying gave the following result:

$$MR = 0.583 e^{-\frac{1}{13} t_o} + 0.144 e^{-\frac{1}{94} t_o} \quad (5.5)$$

where t_o is drying time after 95.5 hrs (Figure 5.2b).

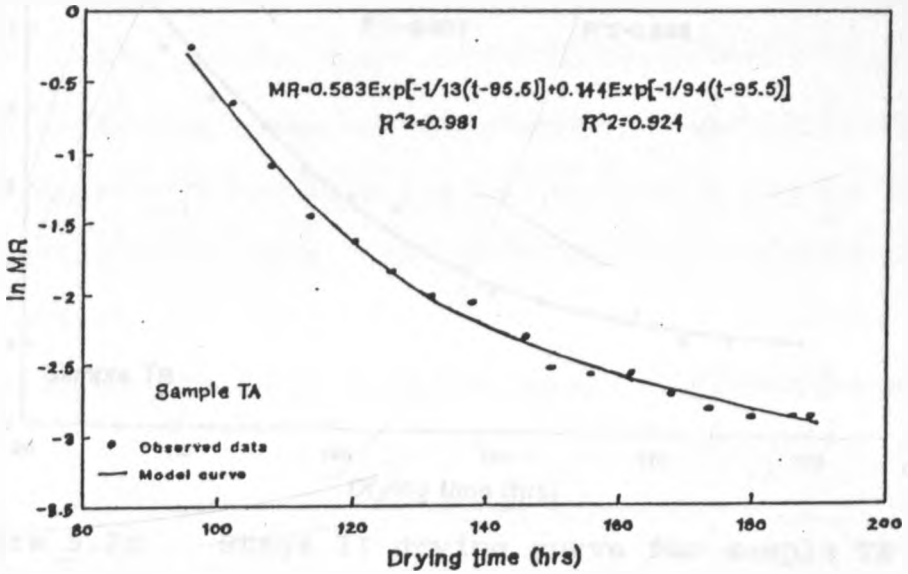


Figure 5.2b Stage II drying parameters for H625/TA

Most of the drying curves show this general behaviour where the first stage of drying is described with a one-term model drying equation. For samples placed at the top of the drying bin where temperatures are much higher during the second stage of drying, two-term model equations are obtained as above, except for

samples at the bottom. Model equation for a sample placed at the top (ie. Sample TB) for variety H625 is given as:

$$MR = 0.642 e^{-\frac{1}{14} t} + 0.106 e^{-\frac{1}{132} t} \quad (5.6)$$

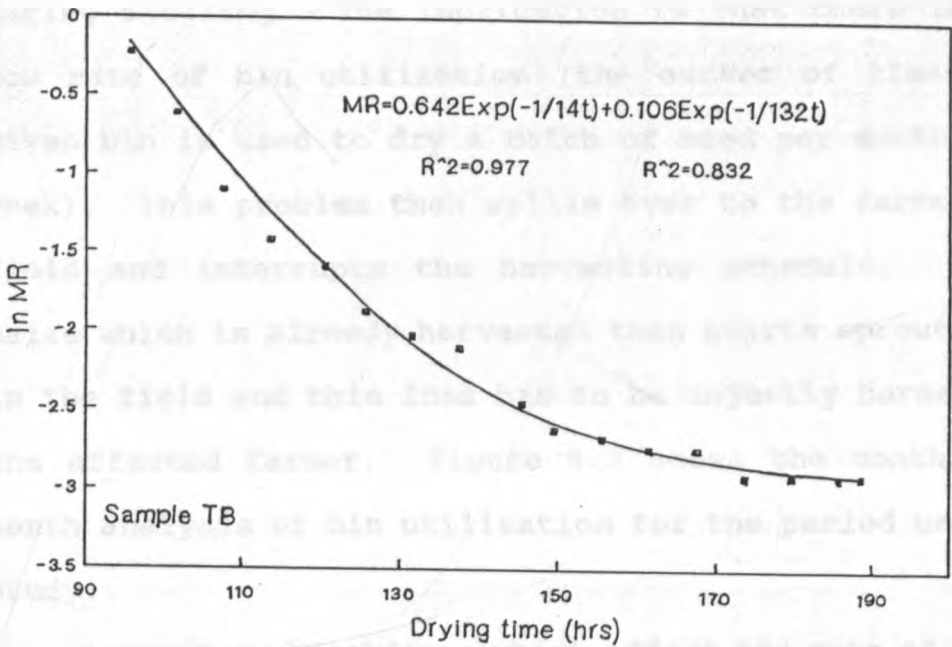


Figure 5.2c Stage II drying curve for sample TB

5.3 Utilization of drying bins.

Bin utilization during the processing season depicts the rate at which wet ears are loaded into the bins for drying and the rate at which the same gets unloaded for shelling. Along the processing channel, from reception of wet ears to the dispatch of dried,

treated and bagged seed, bottlenecks can occur at any point depending on the established system of operation. Frequent breakdowns of the shelling unit leads to a hold-up of dry maize ears in the bins. Such maize then starts to over-dry and mechanical damage then increases during shelling. The implication is that there is a low rate of bin utilization (the number of times a given bin is used to dry a batch of seed per month or week). This problem then spills over to the farmers' field and interrupts the harvesting schedule. The maize which is already harvested then starts sprouting in the field and this loss has to be unjustly borne by the affected farmer. Figure 5.3 shows the month by month analysis of bin utilization for the period under study.

Apart from breakdowns which affect the rate of bin utilization, other factors like conditions of drying (initial moisture content of ears, temperature, humidity, air flow, depth of ears in the bin and the chosen mode of drying- single or double pass) will affect the output of processed seed per day.

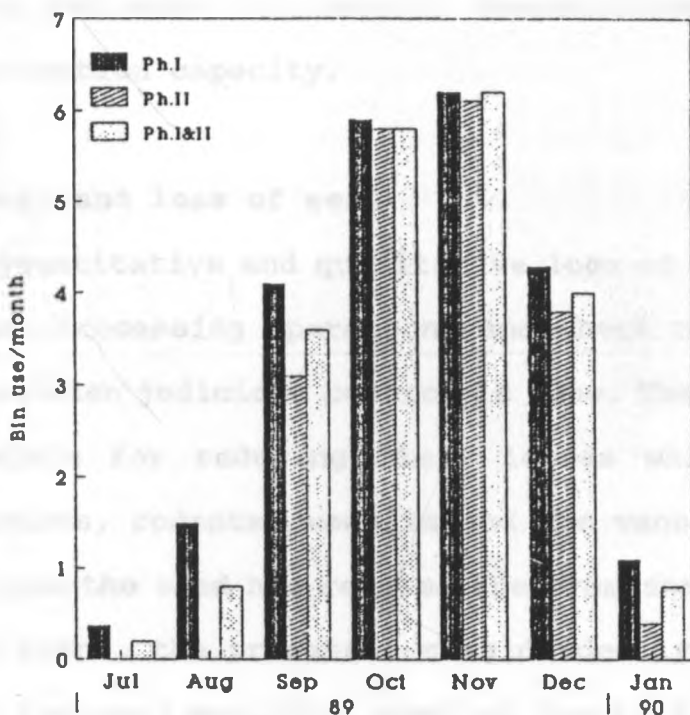


Figure 5.3 Average bin utilization for 1989-90 processing season.

The results of the existing drying system at the Kenya Seed Company has been presented in Section 5.1. The practice is to have approximately 2-metre depth of wet ears in the bins for 72 or more hours. Most of the experimental bins dried for more than twice the design drying hours. A depth slightly smaller than 2m for wetter and small-sized maize varieties could increase the drying speed without necessarily altering the air temperature. The quantity of seed dried should then be compared with the quantity under the previous system.

The added advantage of this would be the shortened time of exposing wet ears to elevated temperatures which affect germination capacity.

5.4 Damage and loss of seed.

Both quantitative and qualitative loss of seed do occur during processing operations and these can only be minimized when judicious control is done. The farmer is responsible for reducing field losses which are caused by birds, rodents, weevils and the vagaries of weather. Once the seed has reached the premises of the processing plant, the processor should ideally strive to enhance the seed quality. Most of the rotten ears have to be removed; drying has to be done to increase storage life; the sheller has to cause as little damage as possible and effective cleaning has to be carried out before the seed is bagged for sale. The results of these operations were analyzed and are presented in the two subsections that follow.

5.4.1 Sheller damage to seeds.

The mechanical sheller used had adjustments for clearance between the rotating cone and the fixed concave. A provision is also made for regulating the flow of dried ears from the intake hopper to the sheller via a gate which is controlled manually. The

gate is moved back and forth in a horizontal plane. The sheller speed of rotation can only be changed by using driven pulleys of varying diameters. The design speed of the sheller is 310 revolutions per minute. Seed damage or loss of whole kernels during shelling is caused by size, type and moisture state of the ears; machine and operator factors.

It was observed that the size of cobs and variations in the speed of the sheller resulted in more damaged seeds. When a lot of ears are allowed to fill the sheller, there is temporary overload and speed momentarily falls. The result is that many ears go unshelled and the shaker shoes then cannot cope with the pre-cleaning necessary at this stage. Hybrid 512 resulted in more damaged seed after shelling than the rest of the varieties studied while H614 and H625 generated more screenings after the cleaning operations. Average percent mechanical damage was 5.01 and 2.06 for varieties H512 and H625, respectively.

When the level of damage was plotted against the speed, no predictable trend was observed (Figures 5.4a,b,c). This was probably due to the unevenness in the loading cycles which could not be controlled. However, a shift in the sheller speed curve to the left by 5 minutes reveals some relationship which could not have been detected in the statistical analysis due to

sampling errors. The sampling was done by estimating the time taken for the shelled grains to reach the sampling point (after the grains had passed through bucket elevators).

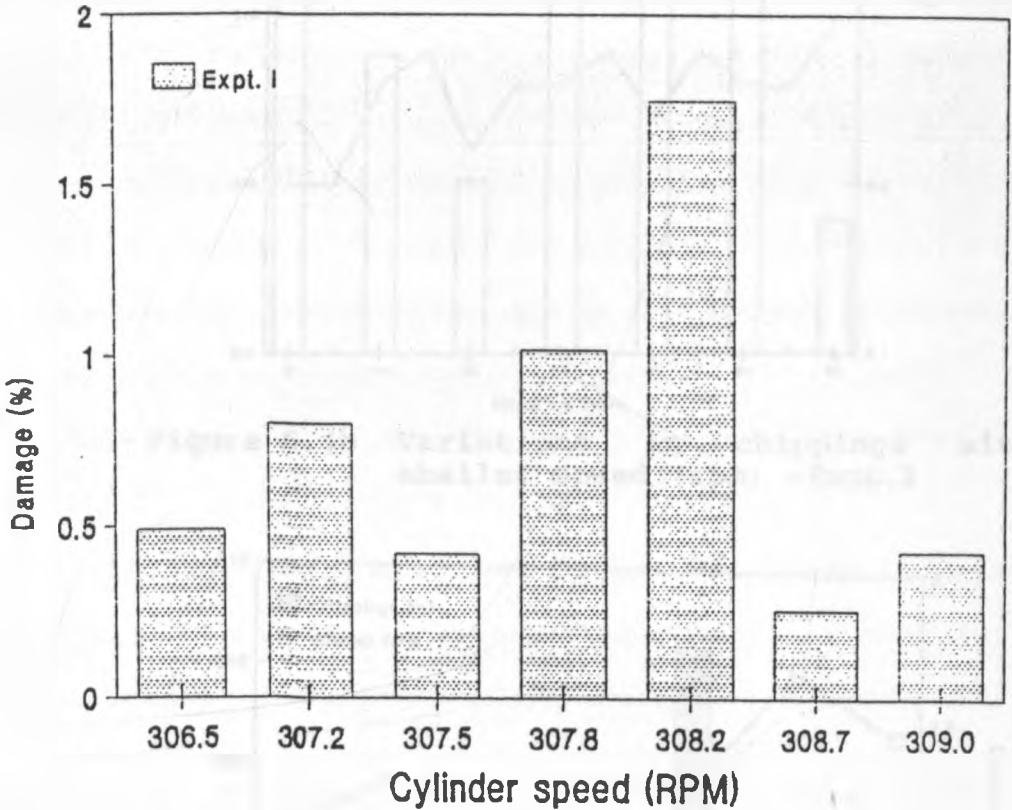


Figure 5.4a Seed damage (%) against speed of sheller (rpm).

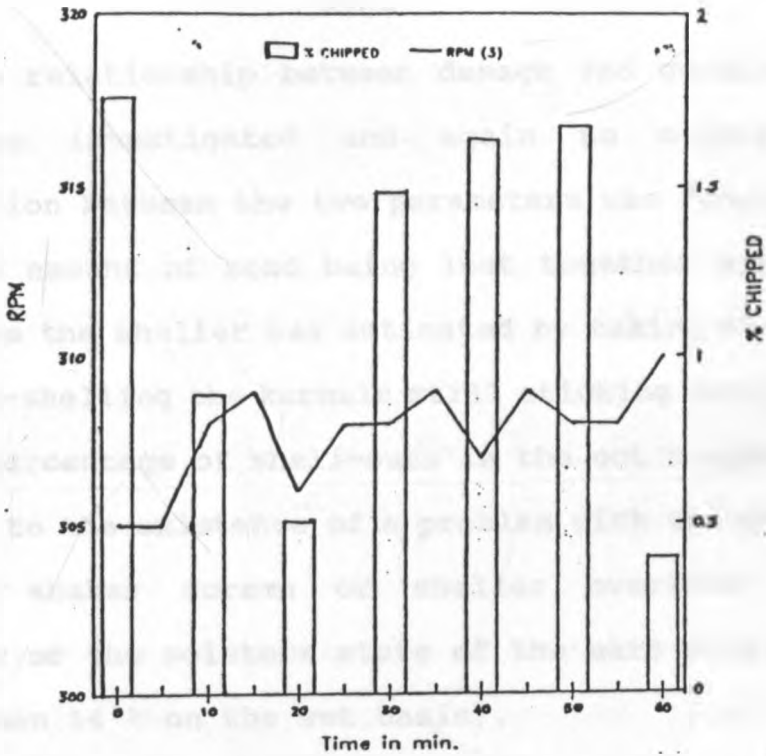


Figure 5.4b Variations in chippings with sheller speed (rpm) -Expt. I

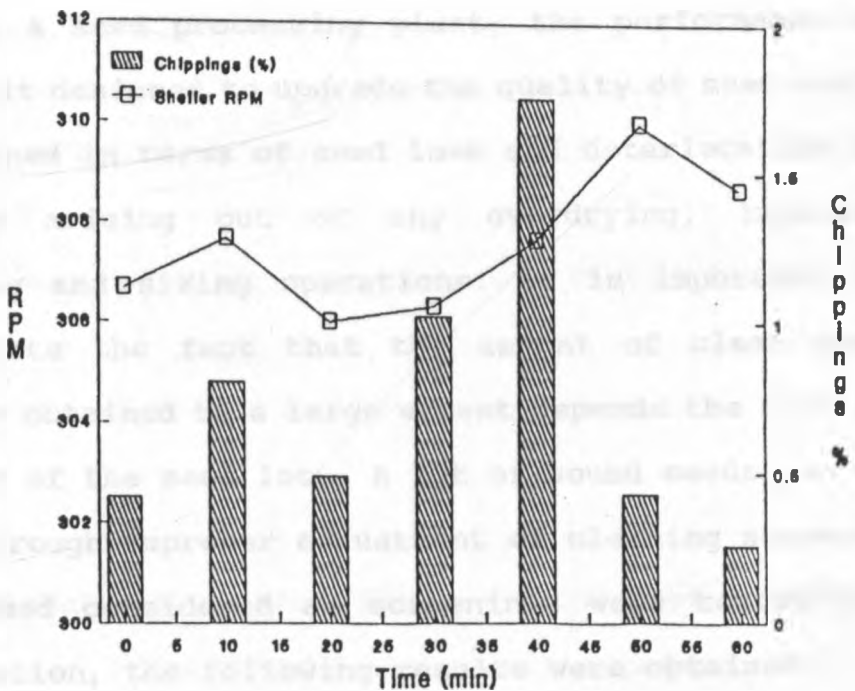


Figure 5.4c Variations in chippings with sheller speed (rpm) -Expt. II

The relationship between damage and germination was also investigated and again no significant correlation between the two parameters was found.

The amount of seed being lost together with the cobs from the sheller was estimated by taking the cobs and hand-shelling the kernels still sticking onto them. A high percentage of shell-outs in the cob hopper is a pointer to the existence of a problem with the sheller (broken shaker screen or sheller overload), the operator or the moisture state of the ears being high (more than 14 % on the wet basis).

5.4.2 Processing factors.

In a seed processing plant, the performance of each unit designed to upgrade the quality of seed would be defined in terms of seed loss and deterioration in quality arising out of any overdrying, improper cleaning and sizing operations. It is important to appreciate the fact that the amount of clean seed finally obtained to a large extent depends the initial quality of the seed lot. A lot of sound seeds can be lost through improper adjustment of cleaning screens. When seed considered as screenings were tested for germination, the following results were obtained:

Kitale Factory Cleanings Report:

Total weight of screenings 500 gms.

Weight of selected seeds 398 gms.

Germination results: 4-day count -nil

7-day count -82%

It was noted that a lot of seeds which are rejected as screenings are actually good and viable. A system which can re-process the screenings is therefore desirable so as to recover the good seed which is otherwise being sold as animal feed material.

Cleaning and sizing operations which lead to the production of size categories of large flat (LF), medium flat (MF) and the heterogenous handplant (HP) depend on the scheduled consumer requirements of these grades for each planting season. However, apart from the Katumani Composite and the Pwani hybrid (PHI) which are produced mainly in the handplant category, the proportions of the other grades were analysed for seed lots of other varieties. Figure 5.5 shows the proportions of LF, MF and HP in seed samples analyzed.

The movement of seed from one piece of equipment to another should result in quality enhancement through the removal of dirt, broken grain and any cob particles. The effectiveness of cleaning and sizing operations was analyzed by drawing samples after each process. The results, as shown in figure 5.6, can be

used to rate the performance of each piece or set of equipment(s), especially when it is suspected that there may be dust accumulation or the presence of a hole in the screens. Table 5-4 also gives a summary of measurable factors during processing of maize seed.

Table 5-4 Processing Factors for H8103 in bin 22

a) Weight of wet ear maize (from field), kg	59010
b) Weight of selection rejects, kg	6546
c) Weight of wet ear maize (in bin), kg	52464
d) Actual selection factor [c/a]	0.889
e) Weight of shelled maize (dry), kg	31700
f) Weight of dry cobs, kg	8640
g) Weight of dry ears (cobs + grain), kg	40340
h) Amount of moisture removed, kg	12124
i) Total drying time, hours	112
j) Drying speed, kg H ₂ O/hr	108.3
k) Initial moisture content (%wb)	22.0
l) Final moisture content (%wb)	12.1
m) Percentage points of water removed	9.9
n) Percentage points of water removed/hour	0.088
p) Moisture extracted per kg. of wet ears (Drying Rate - DR)	0.231
q) Theoretical moisture extracted per kg. of wet ears	0.099
r) Actual Shelling Percentage (ASP) (shelled maize/dry ears)	0.768
s) Theoretical dry ears, kg	47270
t) Theoretical Shelling Percentage (TSP) (kg. shelled maize/theoretical dry ears)	0.671
u) TSP from bag sampling method: 35.1/(44.7 + 9.6)	0.646

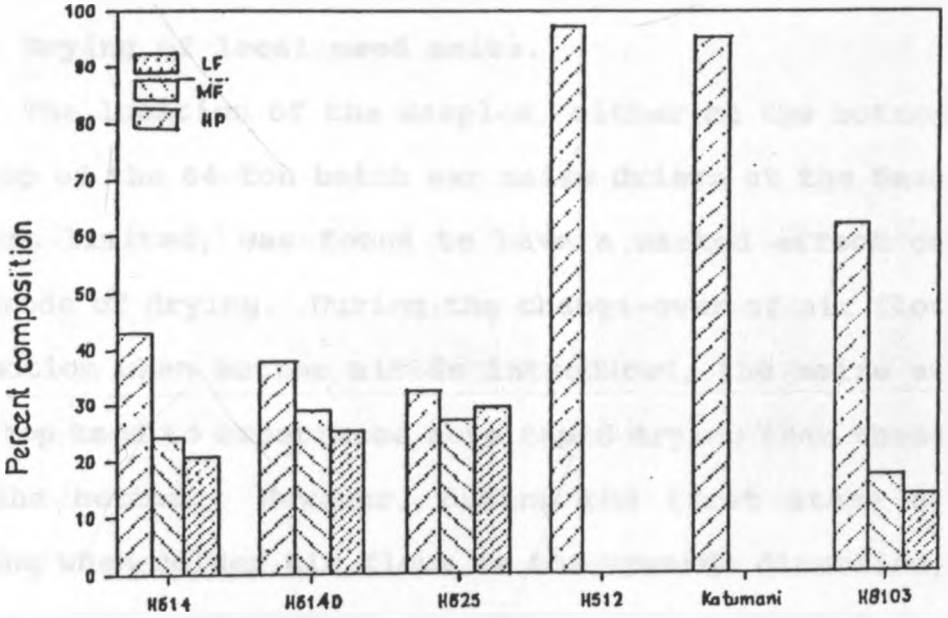


Figure 5.5 Size categories in seed lots.

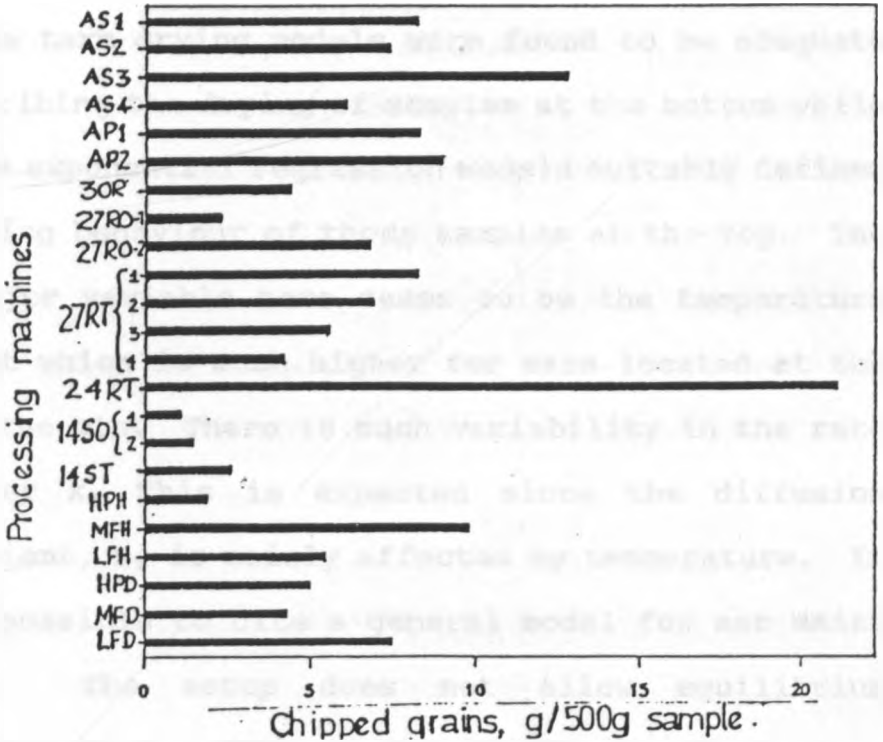


Figure 5.6 Quality enhancement during processing.

6.0 CONCLUSIONS.

6.1 Drying of local seed maize.

The location of the samples, either at the bottom or top of the 64-ton batch ear maize driers at the Seed Driers limited, was found to have a marked effect on the mode of drying. During the change-over of air flow direction when hotter air is introduced, the maize at the top tend to experience more rapid drying than those at the bottom. However, during the first stage of drying when colder air flows in the upwards direction, maize at the top tend to experience some degree of re-wetting especially if the initial moisture content is high.

One term drying models were found to be adequate in describing the drying of samples at the bottom while two term exponential regression models suitably defined the drying behaviour of those samples at the top. The only major variable here seems to be the temperature gradient which is much higher for ears located at the top of the bin. There is much variability in the rate parameter k . This is expected since the diffusion coefficient, D , is mainly affected by temperature. It is not possible to cite a general model for ear maize drying. The setup does not allow equilibrium conditions to be attained, especially when there is a lot of maize to process within season.

Maize ears drying at the top of the bin where they are exposed to temperatures close to 40°C show increased vigour. Bulk ears at the bottom of the bin which are exposed to warm and near-saturated air from another wet bin remain wet for long periods. This delayed 'drying' may be the cause of decreased vigour. Effective drying of maize for seed must start soon after harvesting.

The two pass method does not result in shortened time of drying. Drying rate can be improved by using single pass system, reducing the bed depth and maintaining the temperatures between 40-44°C.

6.2 Effect of drying on seed quality.

Most of the tests used for determining the germination capacity of maize seed dried with hot air appear to be very insensitive in detecting any deleterious effects of drying treatments. Out of the methods used in this work to quantify loss in germination, growth curves give measurable and fairly reproducible results. The Vigour Index can also be used in place of growth curves which require some simple computing and statistical work. In many seed quality control laboratories, these fairly simple procedures have not been instituted. So even though the traditional percentage germinated seed (PGS) is

less accurate, it will possibly continue to be popular with seed testing authorities. This, however, is not without reason since the method is simple, cheap and less time consuming. In case of any 'problem seed lot' or a new variety suspected to be susceptible to heat damage, a more objective and rigorous test is needed.

6.3 Mechanical damage to seeds.

Stress cracking, as defined in section 2.1.3 and 3.4, was non-existent or unobservable in the locally grown maize ears which are dried for seed. Mechanical damage is the main problem with seed maize processing at the Kenya Seed Company. The manufacturers of the Gustafson #1600 high capacity sheller recommend that it should be operated at about 100% full at minimum shelling cylinder speed for the capacity needed and with a good cob removal system. The present assembly of the sheller cannot allow all the mentioned factors to be enforced. The operators are unable to regulate the flow of maize into the sheller since the ears create a bridge at the horizontal control gate. The separation of cobs from seeds at the shaker shoes becomes ineffective due to frequent overload. The control gate must be angled to avoid bridging and the shaker shoes modified in order to minimise damage and general loss of good seed.

7. SUGGESTIONS FOR FURTHER WORK.

Items 1-4 should be looked at critically and implemented by the Kenya Seed Company. The last four aspects are considered as possible areas for future research.

1. Drying time can be reduced by using half the bed depths currently being used (amounting to about 40 tonnes of wet ears per bin), a one-pass air flow system and maintaining drying temperature between 40-44°C.
2. The cob removal system of the sheller should be redesigned to improve recovery of shelled maize. The flow control gate of the sheller should be angled to avoid bridging of maize from the surge hopper.
3. Maximum care should be taken at gravity drops, especially when the maize is still wet. There is need to analyse the damage inflicted on ear maize at the truck dumps and when filling the drying bins.
4. Bin utilization can be improved if the harvesting schedule is adhered to and scheduling of processing operations studied to identify bottleneck points.

5. There is need for controlled environment studies on variables affecting the level of damage during shelling.
6. In order to adequately model the loss in germination of seed maize, the viability constants K_E , C_W , C_H and C_Q in equation 3.26 need to be determined.
7. The first stage of the present two-pass drying system should take as short a time as possible. Delayed drying of wet maize meant for seed lowers germination capacity and seedling vigour.
8. A model ear maize drier, especially for basic seed, should be developed for further research on specific drying behaviour and quality attributes of new varieties.

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Author	Year	Journal	Volume	Page
Woodstock, L.W.	1973	Seed Sci. & Technol.	1	127-157

1. The following information is required for the preparation of a reference list:
2. Author's name
3. Year of publication
4. Title of the article
5. Name of the journal
6. Volume and page numbers

9. APPENDICES.

Appendix A: Recommended drying temperatures.

(Source: Nellist, 1978).

Grain	Purpose	M _o , % w.b.	Inlet Temperature of drying air °C		Final grain temperature
			Continuous drying	Batch drying	
<u>United Kingdom</u>					
All grain	Stock feed		82-104 (a)	82-104 (a)	
Wheat	Milling	< 25	66	66	-
Barley	Malting	> 25	60	60	-
All grain	Seed	< 24	49	49	-
Oilseeds	Oil extraction	> 24	43	43	-
		-	46	-	-
<u>Sweden</u>					
All grain	All purposes	20	65	60	
		25	60	65	-
		30	55	60	-
Wheat and rye	Milling	> 22	-	-	-
<u>France</u>					
All grain	Seed	-	-	-	
Barley	Malting	-	40-42	40-42	30
Oilseeds	Oil extraction	-	-	-	
Wheat	Pasta & Milling	-	80	60	45
	Industrial processing (dry and wet milling)	-	80-90 (b)	-	60
		-	100-110 (c)	-	
	Animal feed	-	100-110	-	65-70
<u>West Germany (e)</u>					
Wheat	Seed or milling	< 18	-	-	46
Barley	Seed or malting	18-20	60-68	-	40
Oilseeds	Seed or oil extraction	> 20	-	-	36
Grain	Feed	-	-	-	66-75
Maize	Feed	< 35	90-99	-	-

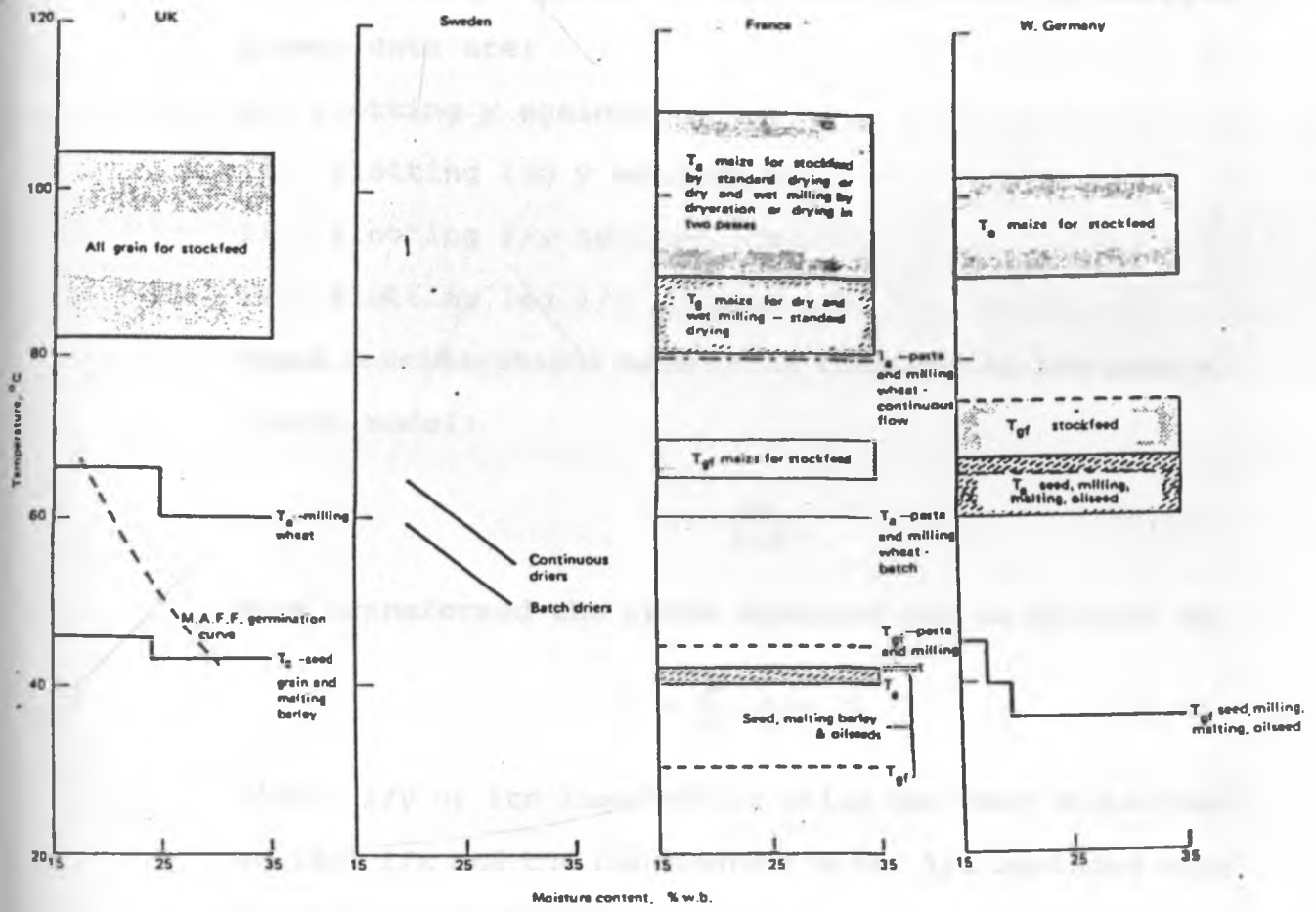
(a) Recommendation contains the rider:- 'Feeding properties are not harmed by temperatures up to 104°C during drying; but the higher the temperature used the more difficult it is to cool the grain effectively before storage.'

(b) Standard drying

(c) 'Dryeration' and drying in 2 passes

(d) These temperatures are defined as 'maximum heat in material being dried' i.e. measured at the hottest zone of the drier. Normally this will be the same as the final temperature prior to cooling

(e) Directly-heated hot-air driers not allowed because of danger of combustion gas residues.



Appendix B:

Germination and growth models.

Four possible equations that can be used to analyse growth data are:

- i) Plotting y against x
- ii) Plotting $\log y$ against x
- iii) Plotting $1/y$ against $1/x$
- iv) Plotting $\log 1/y$ against $1/x$

These considerations arise from considering the general growth model:

$$y = \frac{ax}{k+x} \quad (9.1)$$

When transformed the above equation can be written as:

$$\frac{1}{y} = \frac{k}{a} \left(\frac{1}{x} \right) + \frac{1}{a} \quad (9.2)$$

Either $1/y$ or its logarithmic value can then be plotted against $1/x$ and the constants k/a and $1/a$ replaced with B and C , respectively, to give:

$$\frac{1}{y} = B \left(\frac{1}{x} \right) + C \quad (9.3)$$

Germination data: Hybrid 625 Bin 29.12.89/23

Time t to start of germination = 168 hours.

Sample B1

$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(9.333 - \frac{t}{15.6}\right) \quad (9.4)$$

Sample B2

$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(6.6 - \frac{t}{25.6}\right) \quad (9.5)$$

Sample B3

$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(5.42 - \frac{t}{22.2}\right) \quad (9.6)$$

Sample T1

$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(10.08 - \frac{t}{15.9}\right) \quad (9.7)$$

Sample T2

$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(6.3 - \frac{t}{20.4}\right) \quad (98)$$

Sample T3

$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(13.03 - \frac{t}{11.8}\right) \quad (9.9)$$

From the above equations, average growth curves can be obtained to describe the behaviour of samples dried at the bottom against those which were placed at the top of the bed of maize ears.

For bottom samples, the equation obtained is of the form:

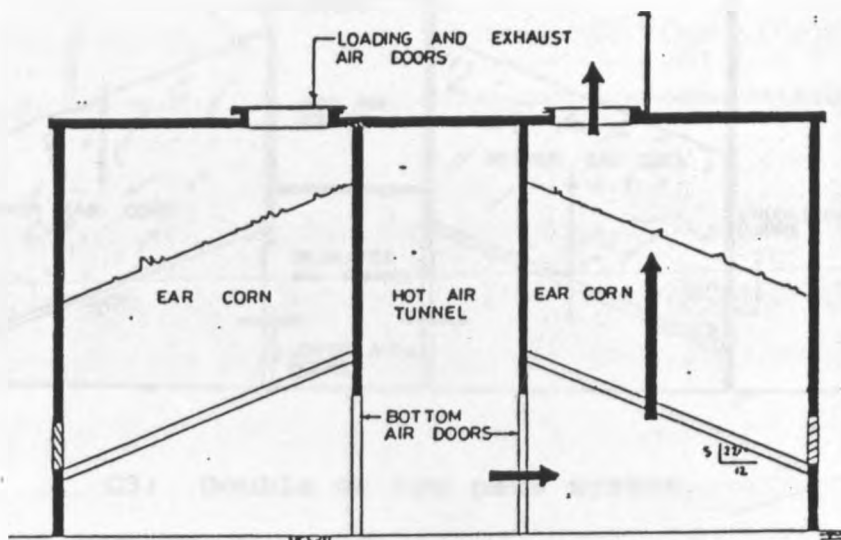
$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(6.02 - \frac{t}{24.4}\right) \quad (9.10)$$

The corresponding equation for samples at the top is:

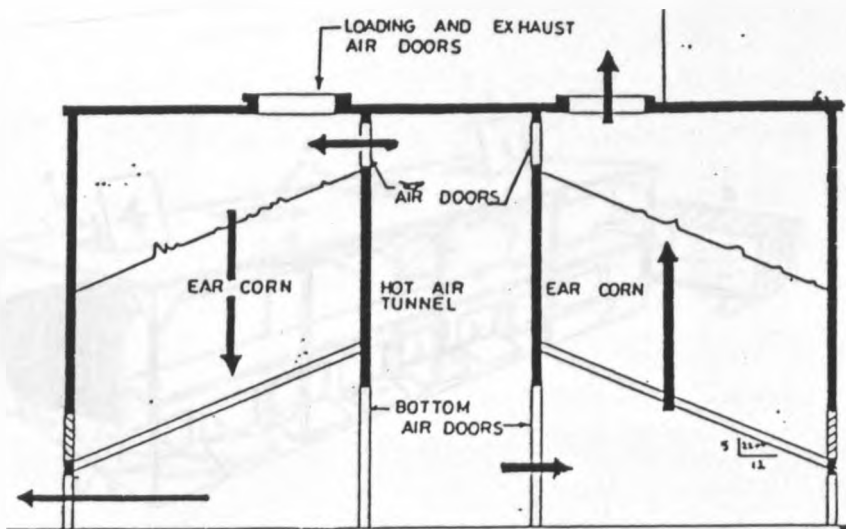
$$\ln\left(\frac{50}{\text{no. germinated after } t}\right) = \text{Exp}\left(8.73 - \frac{t}{17}\right) \quad (9.11)$$

Appendix C1-C4

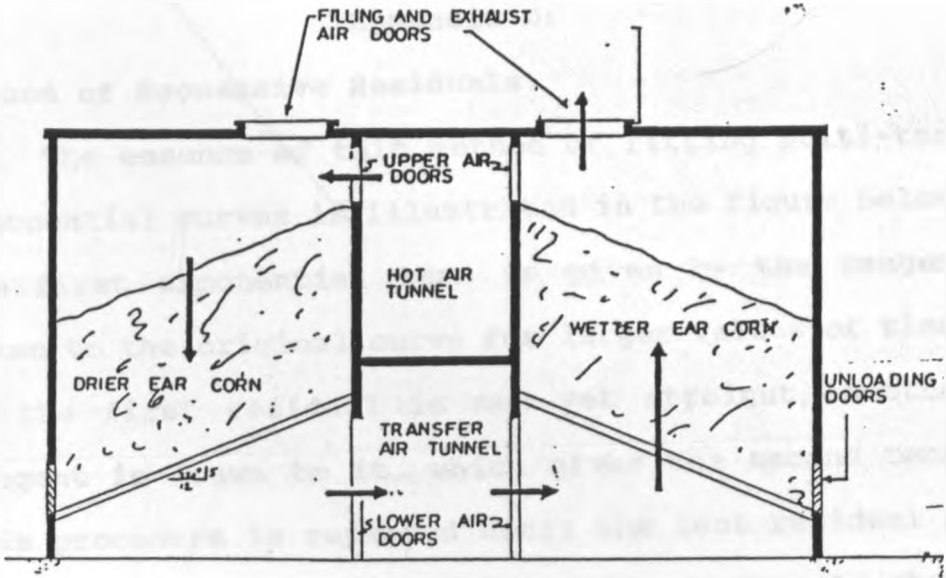
Ear maize drying systems.



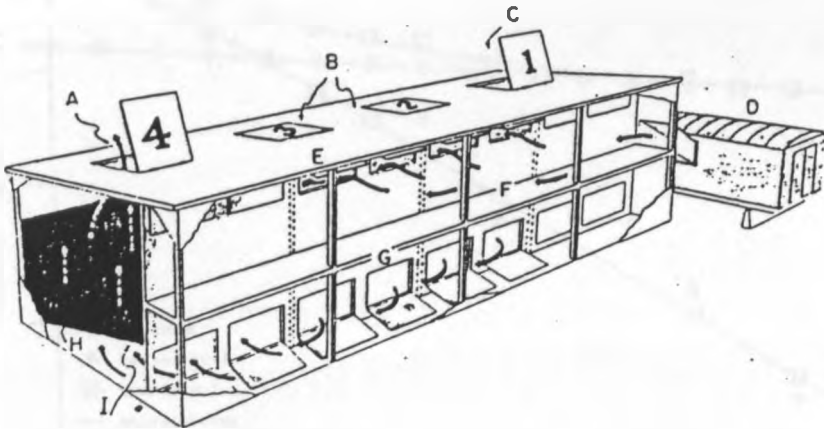
C1: Single pass system.



C2: Single pass reversing system.



C3: Double or two pass system.



C4: Schematic view of C3 showing air flow system.

Appendix D:

Method of Successive Residuals.

The essence of this method of fitting multi-term exponential curves is illustrated in the figure below. The first exponential term is given by the tangent drawn to the original curve for larger values of time. If the first residual is not yet straight, another tangent is drawn to it, which gives the second term. This procedure is repeated until the last residual is sufficiently straight to give the last term. As shown in this example, the second term is fairly straight and so a two-term model adequately describes the material behaviour. The general expression then becomes:

$$MR = 0.658 e^{-0.0785t} + 0.127 e^{-0.0102t} \quad (9.12)$$

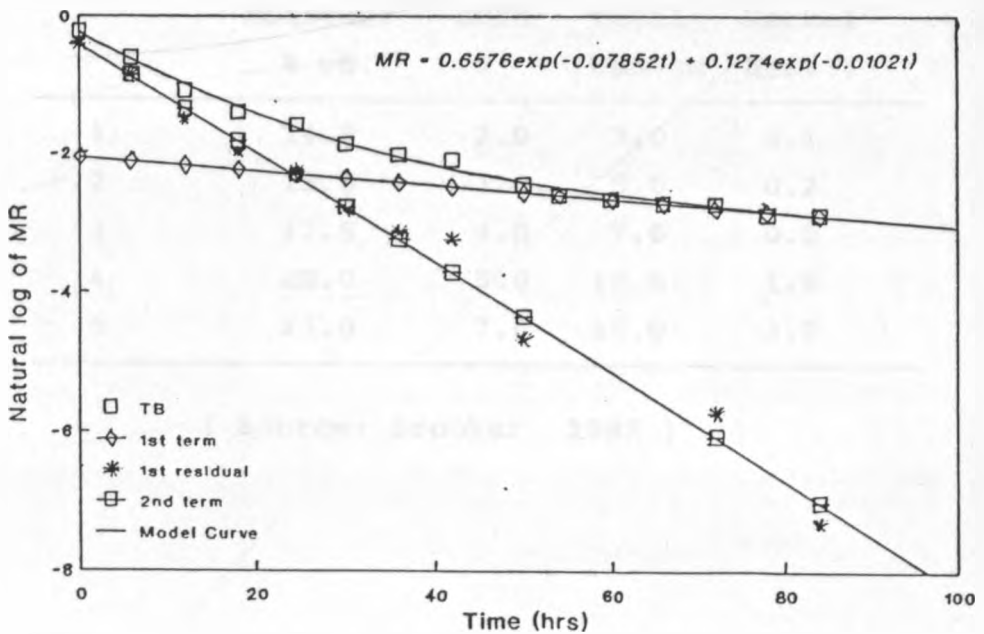


Figure 9.1 Method of successive residuals.

Appendix E.

Table 9-1. Suggested maximum temperatures for drying seed.

Crop	Initial MC (% wb)	Temperature of air reaching seed
Wheat, barley, oats	Over 24	44°C
	Below 24	49°C
Brassicas and clovers	18-20	27°C
	10-17	38°C
Peas	Over 24	38°C
	Below 24	43°C
Soybean	20	40°C
Maize (dried on the cob)	25-40	35°C
	Below 25	40°C

(Source: Kelly, 1988).

Table 9-2 USDA Official Grade Requirements for Corn.

Grade	Maximum limits of			
	Moisture % wb.	BCFM %	Total Damage	Kernel Heat %
1	14.0	2.0	3.0	0.1
2	15.5	3.0	5.0	0.2
3	17.5	4.0	7.0	0.5
4	20.0	5.0	10.0	1.0
5	23.0	7.0	15.0	3.0

(Source: Brooker, 1982)

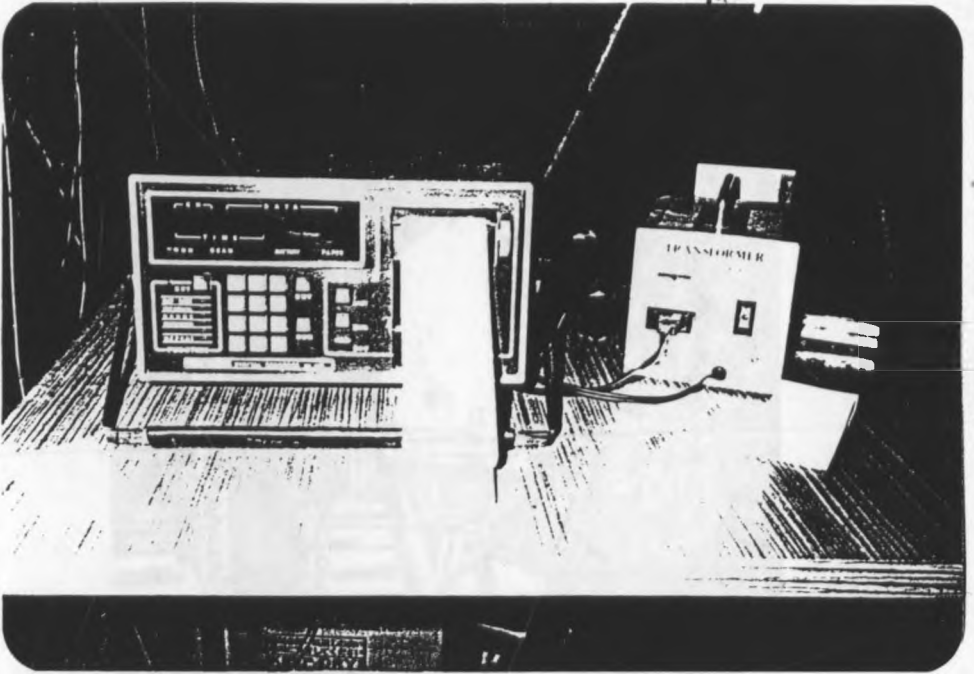


Plate 9.2 Proccos 110 data logger for temperature recording

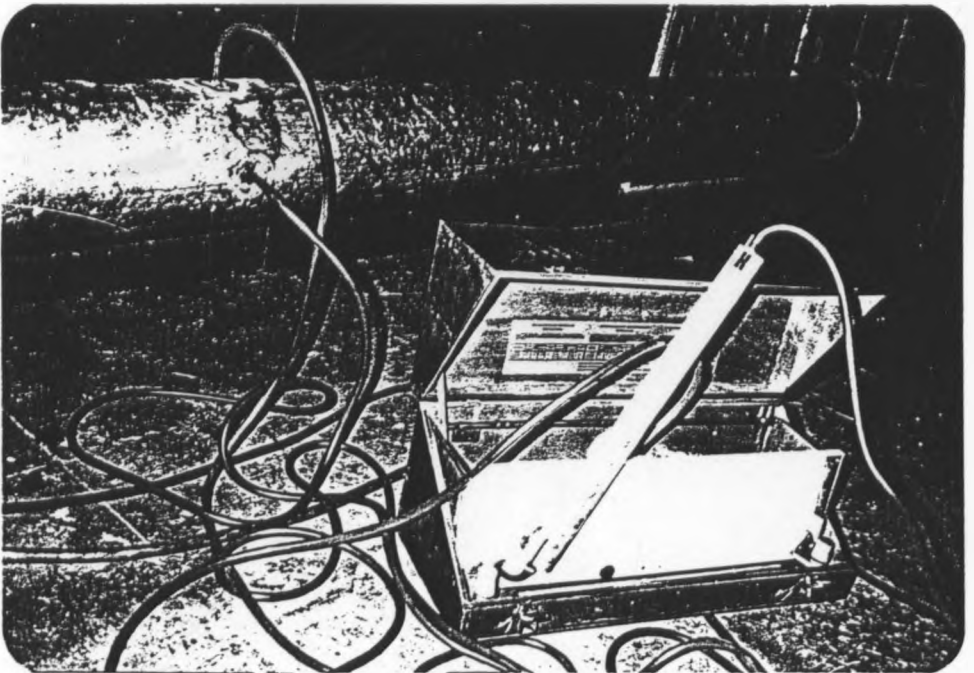


Plate 9.3 Pitot tubes for airflow measurements

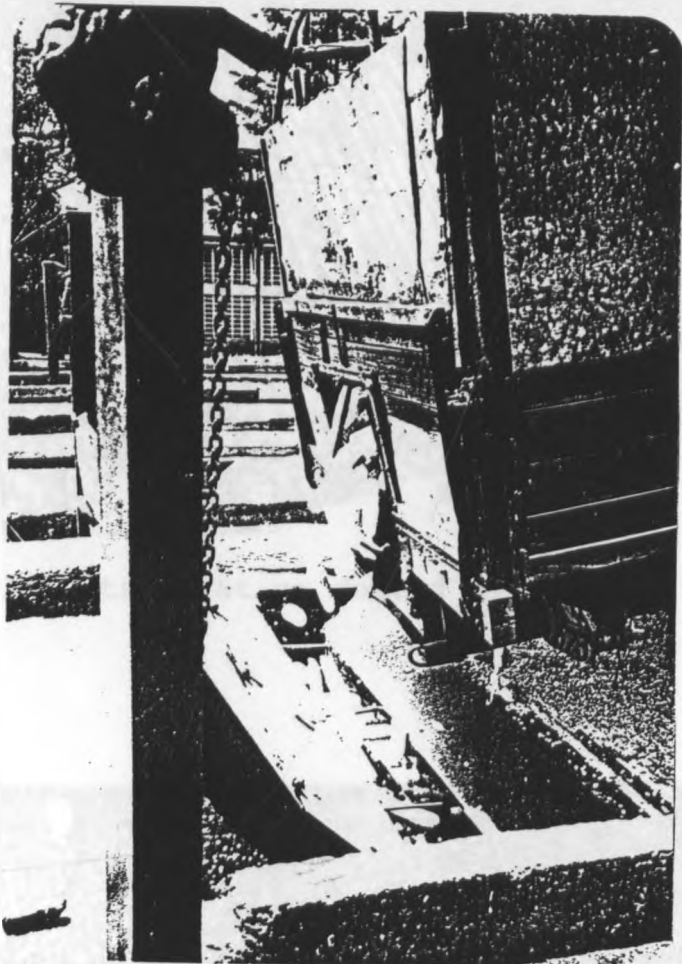


Plate 9.4 Impact at dumping pits
(mechanical unloading)

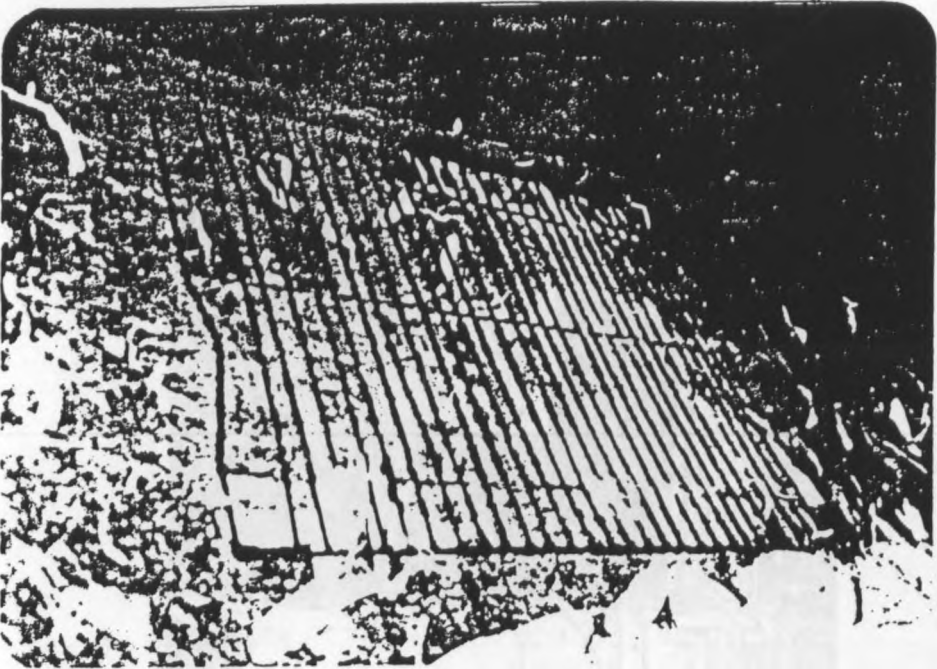


Plate 9.5 Metal grating dented by falling maize

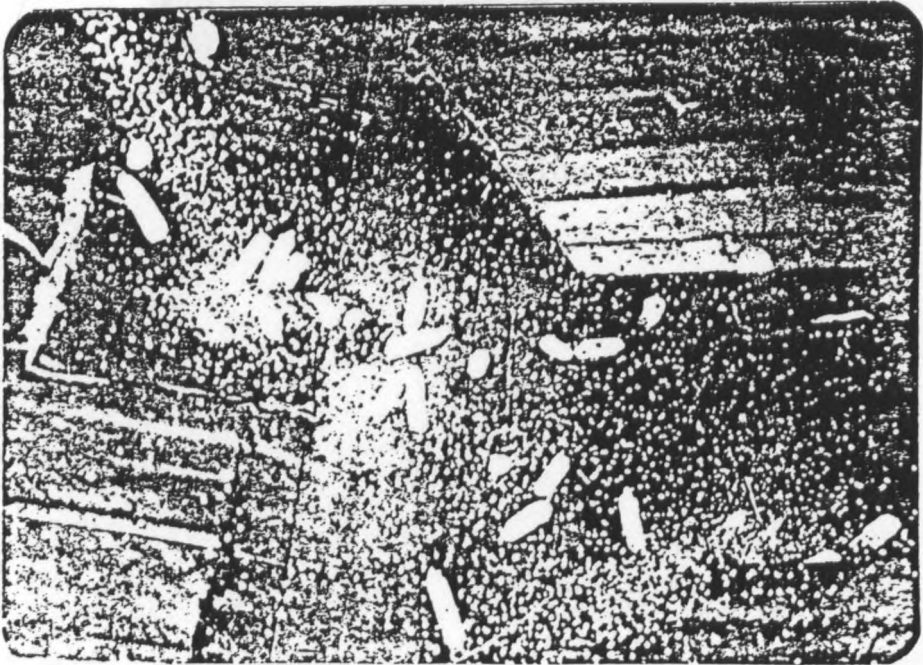


Plate 9.6 Shell-outs caused by high velocity impacts

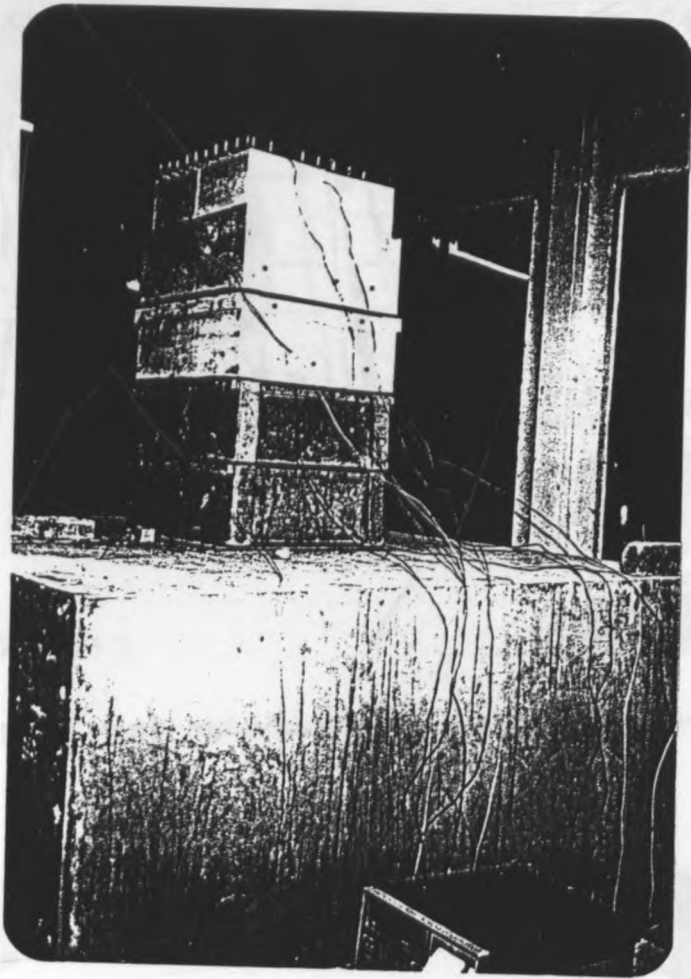


Plate 9.7 Laboratory setup for
tray drying

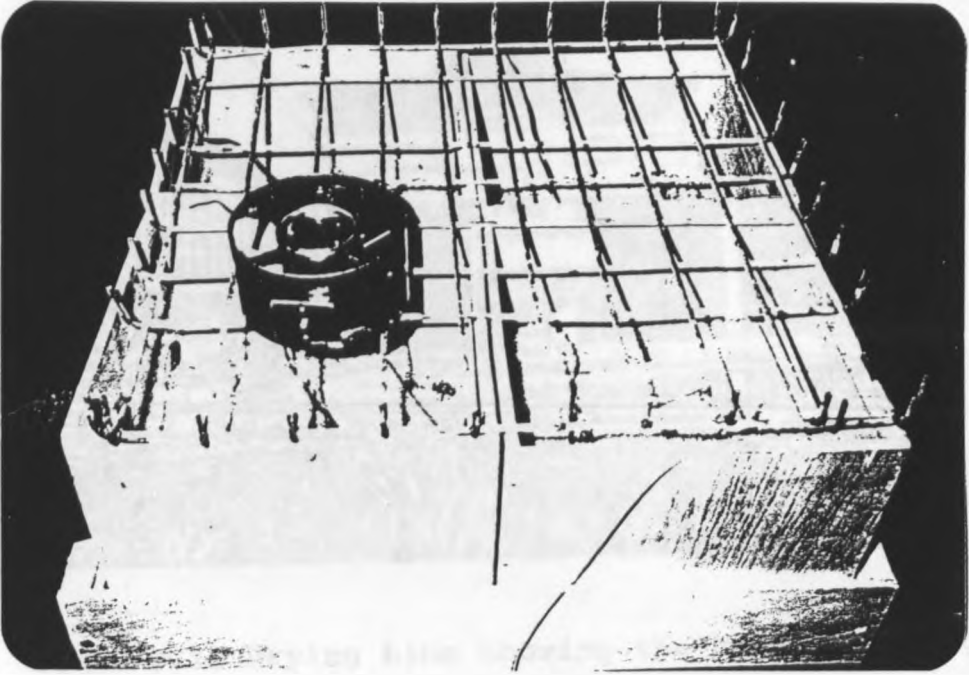


Plate 9.8 Vane anemometer for airflow measurements

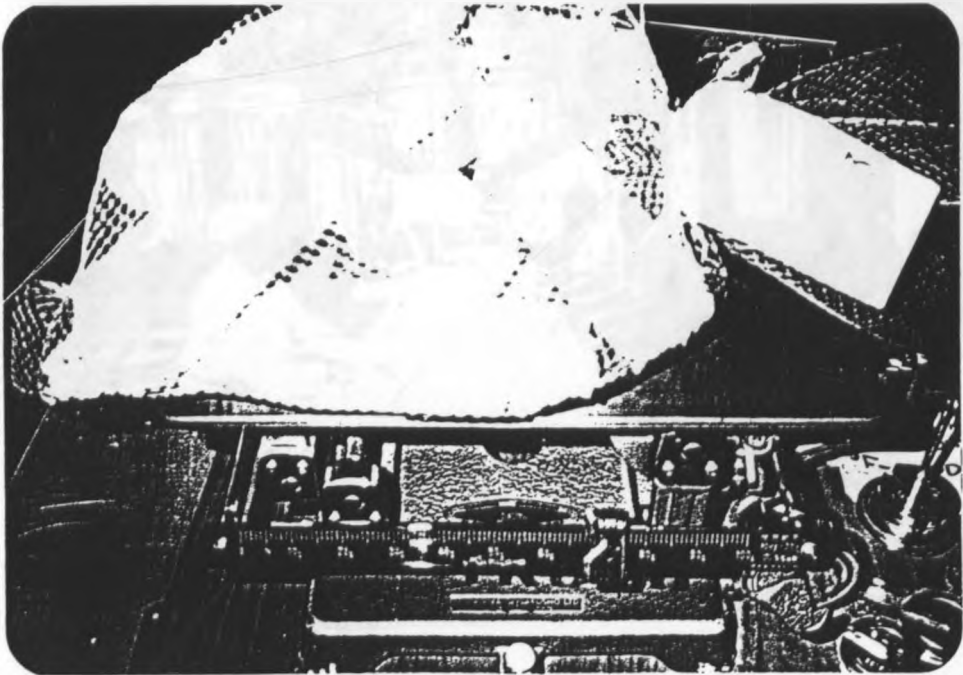


Plate 9.9 Perforated onion nets for drying samples

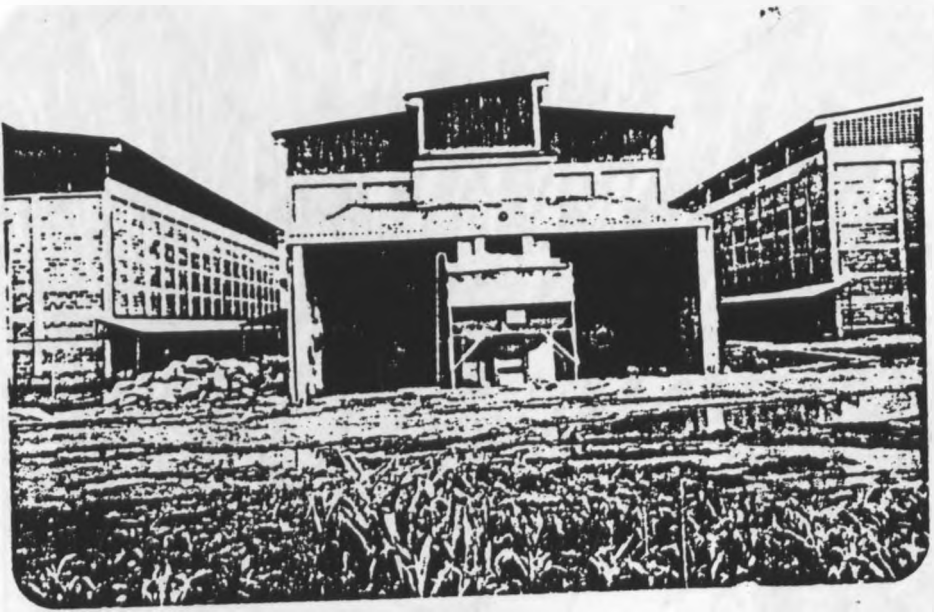


Plate 9.10 Drying bins showing the burner housing

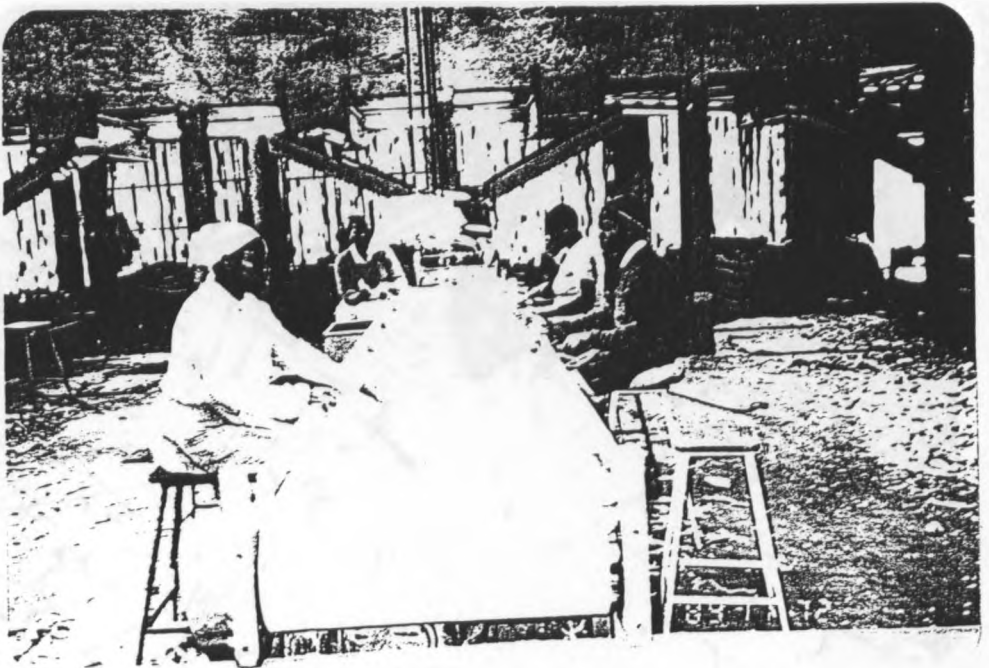


Plate 9.11 Selection of rotten ears, off-types, males and diseased ears

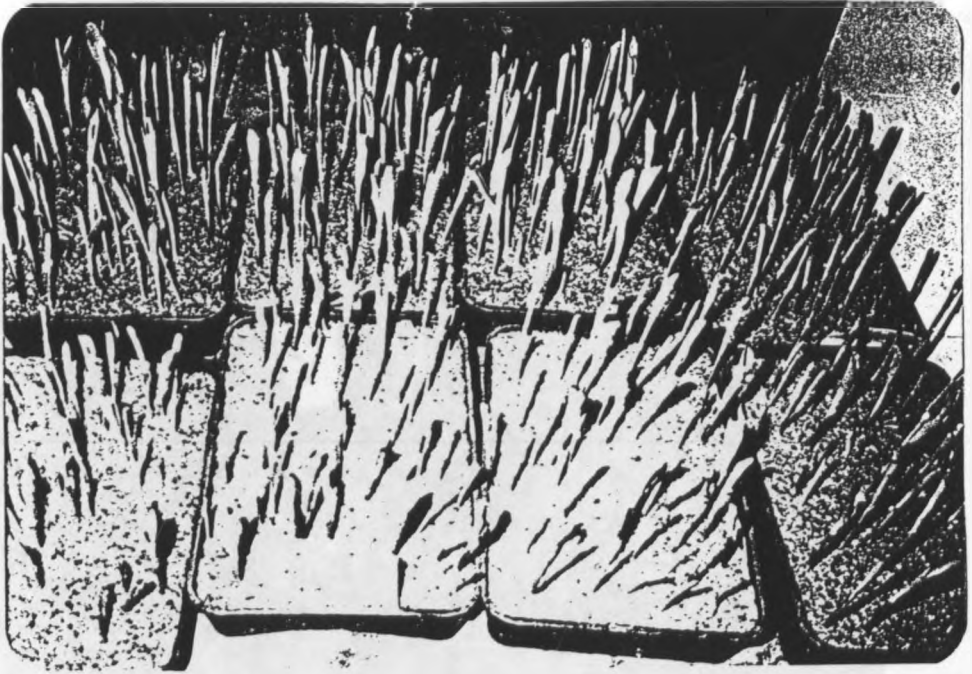


Plate 9.12 Germination experiment in sand medium

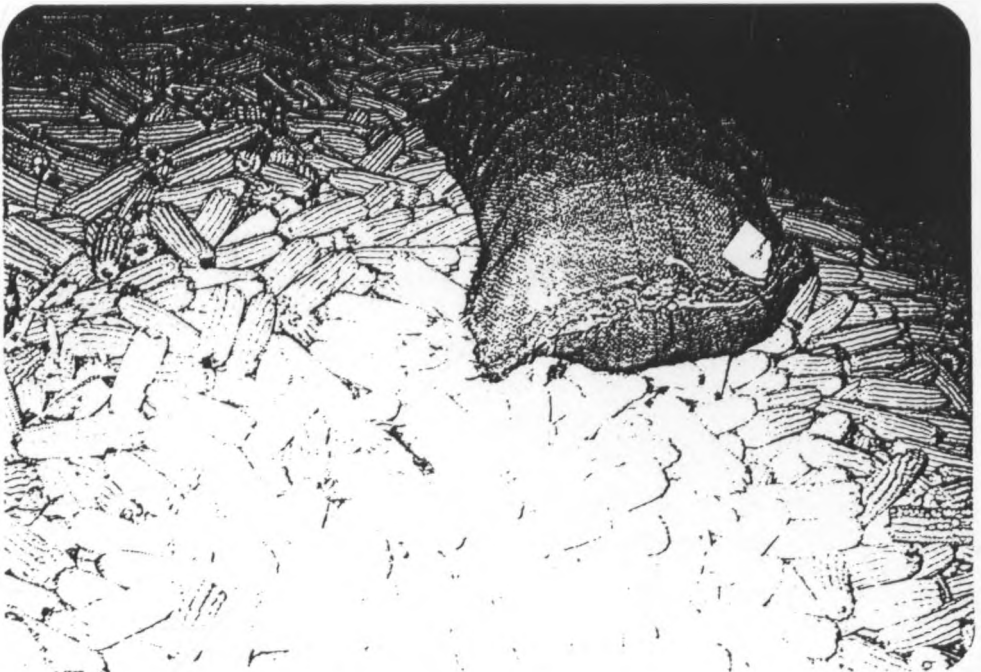


Plate 9.13 Bag sample for determining "drying factors"

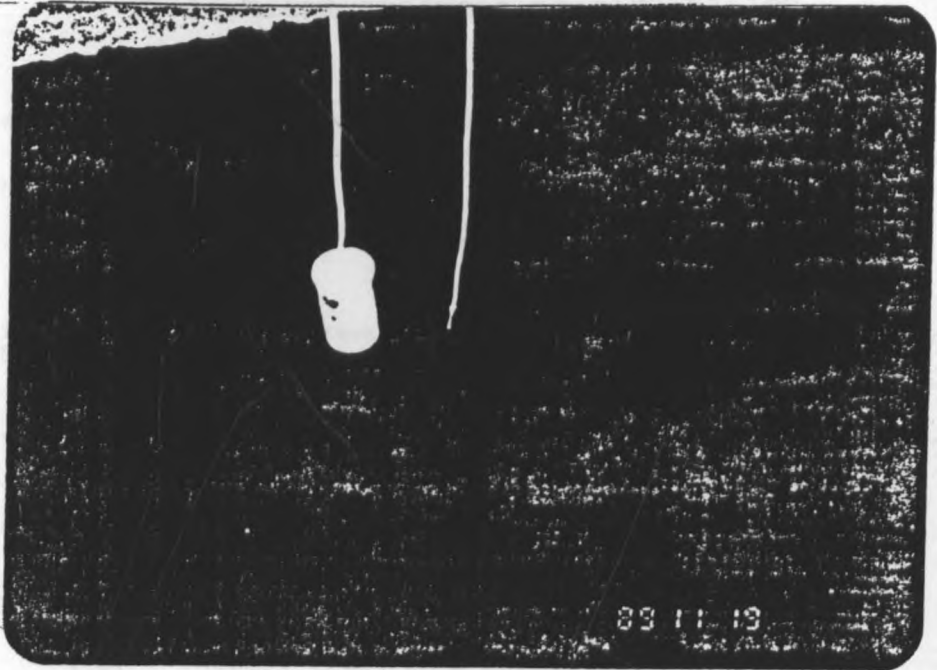


Plate 9.14 Modified "wet bulb" temperature sensor

Appendix G.
Statistical analysis of germination.

ANALYSIS OF GERMINATION H625 BIN 9-17.12.89/23

Model Equation: $\text{Log [1/\% Germination]} = a + b/\text{time}$

where a and b are constants.

Top samples: $Y=7.12X-1.81$

$Y = \text{Log}[1/\% \text{Germination}]$ and

Bottom samples: $Y=7.06X-1.787$

$X = 1/\text{time (hrs)}$

BOTTOM (B)	TOP (T)	D=T-B	d= D+0.0219)	SQUARED DEVIATION, d ²
-0.874	-0.890	-0.016	0.006	3.45E-05
-1.122	-1.140	-0.018	0.004	1.50E-05
-1.385	-1.405	-0.02	0.002	3.52E-06
-1.743	-1.766	-0.023	-0.001	1.27E-06
-1.81	-1.833	-0.023	-0.001	1.27E-06
-1.893	-1.917	-0.024	-0.002	4.52E-06
-2.033	-2.058	-0.025	-0.003	9.77E-06
-2.097	-2.123	-0.026	-0.004	1.70E-05
			0	8.69E-05
-1.6	-1.6	-0.0219		

A	$\{\text{Summation } d^2\}/(n-1)$	1.24E-05
A/n	$\{\{\text{Summation } d^2\}/(n-1)\}/n$	1.55E-06
$\{A/n\}^{0.5}$		1.25E-03

For a test of hypothesis that the two locations on average result in equal rate of germination,

Calculated t -17.563 **

From a two-tailed test for the t-statistic, the following result is obtained.

Confidence level 7 d.f.	0.5	0.05	0.01	0.001
Tabulated t	0.711	2.365	3.499	5.405

The data therefore point to a superiority of samples dried at the top.

GERMINATION ANALYSIS: H8103

BOTTOM (B)	TOP (T)	D=T-B	d=D-2.3	SQUARED DEVIATION, d ²
29.7	32.3	2.6	0.3	0.09
47.8	46.6	-1.2	-3.5	12.25
60.8	64.9	4.1	1.8	3.24
72.6	83.1	10.5	8.2	67.24
81.7	86.9	5.2	2.9	8.41
90.4	92.0	1.6	-0.7	0.49
95.5	95.0	-0.5	-2.8	7.84
96.2	95.9	-0.3	-2.6	6.76
98.2	96.9	-1.3	-3.6	12.96
			0	119.28
74.8	77.1	2.3		

A -	$[\text{Summation } d^2] / (n-1)$	14.91
A/n	$([\text{Summation } d^2] / (n-1)) / n$	1.657
$(A/n)^{0.5}$		1.287
	Calculated t	1.787 ns

Confidence level	Tabulated t
7 d.f.	
0.05	2.306
0.01	3.355

We cannot reject the null hypothesis.

GERMINATION ANALYSIS: H625 BIN 29.12.89/23

BOTTOM (B)	TOP (T)	D=T-B	d= D-2.5714	SQUARED DEVIATION, d ²
32	35.0	3	0.429	0.184
36	40.0	4	1.429	2.041
40	43.0	3	0.429	0.184
45	48.0	3	0.429	0.184
47	49.0	2	-0.571	0.327
48	50.0	2	-0.571	0.327
49	50.0	1	-1.571	2.469
			$\sum d = 0$	Sum 5.714
42.4	45.0	2.5714		

A	$[\text{Summation } d^2]/(n-1)$	0.952
A/n	$([\text{Summation } d^2]/(n-1))/n$	0.136
$(A/n)^{0.5}$		0.369
	Calculated t	6.971 **

Confidence level		
6 d.f.	0.05	0.01
Tabulated t	2.447	3.707

The difference in germination between top and bottom samples is therefore highly significant.

Table 9-3 Percentage of clean seed in screenings.

Proportions of grains, whole and broken cobs in waste from sheller.

Sample No.	Broken cobs (kg)	Whole cobs (kg)	Cobs total	Dust (kg)	Grains (kg)	Total (kg)
1	4.1	10.9	15.0	0.01	0.46	15.47
2	3.1	12.5	15.6	0.06	0.23	15.89
3	3.5	8.8	12.3	0.04	0.28	12.62
4	3.2	10.8	14.0	0.03	0.45	14.48
5	2.6	9.1	11.7	0.04	0.16	11.90
6	2.8	10.8	13.6	0.04	0.22	13.86
7	2.1	8.9	11.0	0.04	0.33	11.37
8	3.1	8.7	11.8	0.03	0.14	11.97
9	3.8	11.0	14.8	0.03	0.23	15.06
10	3.1	9.0	12.1	0.03	0.44	12.57

Table 9-4 Variation of chipped grain with sheller RPM (Experiment I)

Time (min)	Rep.1 (RPM)	Rep.2 (RPM)	Rep.3 (RPM)	Average Speed	Chipped Grain (%)
0	305	309	306	306.7	0.42
5	308	309	308	308.3	
10	306	309	309	308.0	0.80
15	309	308	307	308.0	
20	306	306	305	305.9	0.49
25	308	305	306	306.3	
30	303	308	306	305.7	1.02
35	309	310	309	309.3	
40	305	310	309	308.0	1.75
45	309	309	308	308.7	
50	310	310	310	310.0	0.43
55	308	308	308	308.0	
60	309	308	309	308.7	0.26

Table 9-5 Variation of chipped grain with
sheller RPM (Experiment II)

Time (min)	Rep.1 (RPM)	Rep.2 (RPM)	Rep.3 (RPM)	Average Speed	Chipped Grain (%)
0	308	308	305	307.0	1.76
5	317	309	305	310.3	
10	309	307	308	308.0	0.89
15	309	306	309	308.0	
20	309	307	306	307.3	0.51
25	308	308	308	308.0	
30	307	308	308	307.7	1.48
35	306	309	309	308.0	
40	310	309	307	308.7	1.64
45	307	309	309	308.3	
50	308	308	308	308.0	1.68
55	308	308	308	308.0	
60	309	308	310	309.0	0.40