MOISTURE SORPTION IN SEED MAIZE (*ZEA MAYS* L.) DURING HERMETIC DRYING USING SUPER ABSORBENT HYDROGEL

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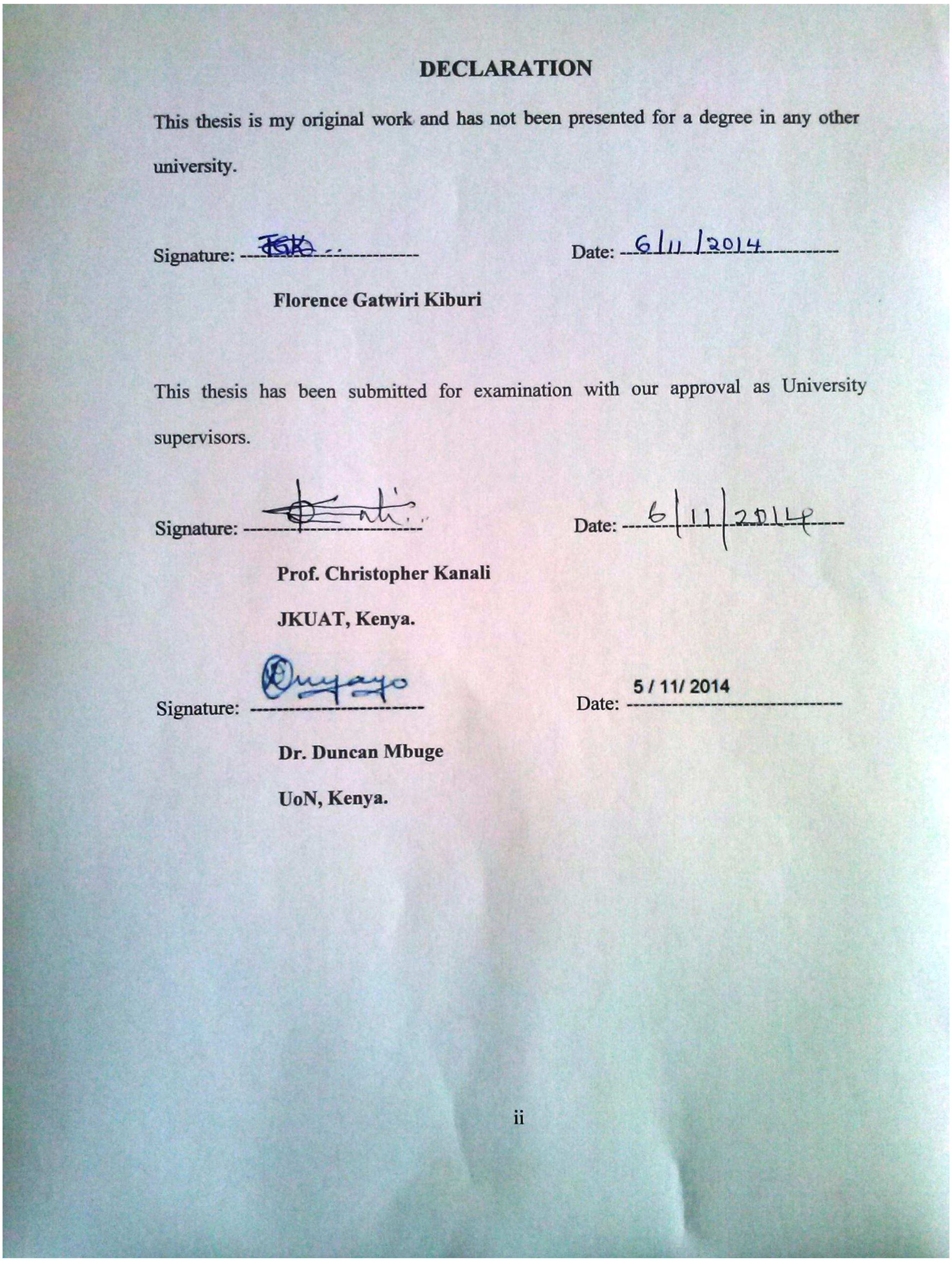

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signature: ------------------------- Date: 6/11/2014

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This thesis has been submitted for examination with our approval as University supervisors.

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Dr. Duncan Mbuge

UoN, Kenya.

DEDICATION

To my family,

I would like to dedicate this thesis to you, my beloved ones.

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Further, I extend my thanks to all my enumerators and all who assisted in development of this thesis and my course mates whose constructive criticism, continuous encouragement, support and hard work helped me work hard. Finally, I am truly indebted to my family who provide me real love, encouragement and inspiration in pursuing masters. God bless you all.

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LIST OF ACRONYMS AND ABBREVIATIONS

a, b, c, g, η	Model's parameters
ANOVA	Analysis of variance
CIMMYT	International Maize and Wheat Improvement Centre
d.b	Dry basis
FAO	Food and Agricultural Organization of the United Nations
ISTA	International Seed Testing Association
k	Drying rate constant (h^{-1})
$\mathbf{M_e}$	Equilibrium moisture content (% d.b)
$\mathbf{M_o}$	Initial moisture content (% d.b)
MR	Moisture ratio
$\mathbf{MR_{exp}}$	Measured moisture ratio
$\mathbf{MR_{pre}}$	Predicted moisture ratio
$\mathbf{M_t}$	Moisture content (% d.b) at drying time *t* (hours)
N and **z**	Number of observations and constant for the model
p	Probability
$\mathbf{R^2}$	Coefficient of determination
RMSE	Root-mean-square error
SAPs	Super Absorbent Polymers
SSR	Regression sum of squares
SST	Total sum of squares
t	Drying time (hours)

$\mathbf{W_d}$	Dry mass (g)
$\mathbf{W_t}$	Mass (g) at drying time *t* (hours)
$\mathbf{W_w}$	Wet mass (g)
χ^2	Chi-square

ABSTRACT

The aim of this study was to establish the feasibility of using super absorbent hydrogel in drying of seed maize (*Zea mays* L.) under hermetic conditions. The study was conducted at the Jomo Kenyatta University of Agriculture and Technology (JKUAT). Seed maize was obtained from East African Seed Company Limited-Industrial area, Nairobi, while the super absorbent polymer, i.e., Poly-acrylic acid, sodium salt and lightly cross-linked used in the study was purchased from Sigma Aldrich® Germany.

The performance of hydrogel was evaluated based on three (3) treatments consisting of 1:5, 1:10 and 1:15 hydrogel to seed maize ratio by weight dried under different seed drying temperatures of 25, 30, 35 and 40^{o}C and initial moisture content of 16, 28 and 53% (d.b); the control did not utilize any hydrogel. The results were analyzed using Analysis of Variance (ANOVA) in order to determine whether there existed significant differences within the drying rate of the different treatments, and also from the control. Modeling was done using non-linear regression analysis (MS Excel 2003^{TM}) based on the minimization of sum of squares by adjusting the model constants. The coefficient of determination (R^2), the Chi-square (χ^2) and the root-mean-square error (RMSE) were used to evaluate the goodness of fit of the five (5) tested mathematical models to the actual data. The models considered for this study were Page, Two term exponential, Newton, Logarithmic and Henderson and Pabis model. The viability of seed maize was evaluated by performing germination test to determine the maximum germination potential of a seed lot after drying using superabsorbent hydrogel under hermetic conditions for different treatments.

The moisture content of seed maize was recorded after seven days of drying with each set of treatment having reduced seed moisture content. A ratio of 1:5 seed maize to hydrogel by weight and drying temperature of 40^{o}C the moisture content of seed maize reduced by 31.1, 15 and 4% for initial seed moisture contents of 53, 28 and 16% (d.b) respectively. The ANOVA results showed that at 1% significance level there were highly significant differences between the final moisture content attained for the drying temperature, ratio and temperature ratio interaction ($p < 0.001$). High values of coefficient of determination ($R^2 > 0.95$) were obtained for all the five drying models while the corresponding values of χ^2 and RMSE were in the range of (0.0016-0.0141) and (0.0400-0.3045) respectively. As a result Logarithmic model was the best fitted model with R^2 (0.9749-0.9876) and the weakest values of χ^2 (0.0016-0.0036) and RMSE (0.04-0.128). Seed drying using hydrogel did not alter seed viability as germination test results revealed germination rates as high as 86.5%.

The results of this study illustrate that hydrogel can be used as a potential desiccant for drying seeds while maintaining their viability.

CHAPTER ONE

INTRODUCTION

1.1. Background Information

Grain drying is important as it removes moisture which may otherwise cause decay, premature germination of seeds or growth of microorganisms, especially during subsequent storage period (Uluko *et al.,* 2006). It is estimated that in the tropics between 25 and 40% of agricultural products such as maize is lost because of inadequate farm and village level drying and storage practices annually (Weinberg *et al.,* 2008; Hayma, 2003). To reduce the challenges of storing seeds with high moisture, Wambugu *et al.,* (2009) found that farmers hang maize cobs over the fire place or sun-dry their harvest and store them in gunny bags. Maize is hygroscopic in nature and tends to absorb or release moisture to the surrounding. These traditional practices of seed drying and storage tend to expose the seeds to moist and humid conditions causing the seed maize to absorb moisture from the surrounding resulting in enhanced deterioration (Devereau *et al.,* 2002).

According to a study conducted by Wambugu *et al. (*2009) in Siaya and Busia Districts of Western Kenya, drying and storage is a priority problem facing on-farm seed production. The study also showed that about 78% of farmers stored their own seeds from one season to another. The study further found that farmers had developed a variety of drying and storage practices. The common storage methods for seed maize included use of gunny bags (55%), plastic containers (24%) and hanging over the fireplace (13%).

Worldwide there is increasing demand for high-quality and safe food and seed, free of chemical and physical contaminants and pathogens. Grain and seed growers and users must maintain high quality of their produce. Maize is usually harvested when its moisture content is in the range of 21.9 to 31.6% dry basis (FAO, 1992). The abiotic and biotic stresses promote growth of toxigenic fungi that produce mycotoxins in maize affecting the seed quality thus lowering the yields (Magan and Aldred, 2007). Therefore, measures on curbing the infestation need to be taken such as improved drying method, use of preservatives and proper storage of produce. Storing properly dried seeds allows farmers to plant more viable seeds and hence get better yields.

Additional studies have also been conducted in Kenya to establish the state of seed maize storage facility (Nielsen, 2012). The studies show that most of the facilities are in poor conditions. The cooling equipments are unmaintained and they often leak through the roof. Some attempts to curb moisture ingression into the facility by use of barriers such as aluminum lining, silica gel and insulation by use of plastic foam have been made (Nielsen, 2012).

There are various drying method practiced widely in the world today among them sun drying, forced air drying and modified solar drying (Ronoh *et al.,* 2009; Agrawal *et* *al*., 1998). Sun drying is limited to days with sufficient sun and requires use of spreading materials such as mats or paved grounds. The method exposes the grains to contamination from animal droppings, leaves and other foreign materials. It is also slower compared to forced air drying as it takes 2 to 4 days for the grain to dry to safe moisture storage (Ronoh *et al.*, 2009; Bakker-Arkema *et al.*, 1999). Sun drying requires a lot of labor as the grains have to be intermittently stirred and covered at night.

High temperature dryers such as cross-flow dryers, mixed-flow dryers, and concurrent-flow or counter flow dryers are classified as high capacity dryers. These high temperature dryers are unable to produce grains of the same high quality as low-temperature in-bin drying systems (Bakker-Arkema *et al.*, 1999). However, the high capacity dryers are best used for drying food grains which requires temperature of about 50 to 55 °C and not for seeds as they lose viability with temperatures above 40^{o}C (Hayma, 2003).

Although airtight storage is not new, the principle behind it needs to be used in designing low cost seed storage containers for resource-poor farmers which will allow them to save enough seeds of high quality for future planting (Wambugu *et al.*, 2009). Storing high moisture seeds in airtight containers leads to mold growth in some of the seeds. The aim of this project was to incorporate both the principle of hermetic drying and storage in order to improve storage life of the seeds. Proper drying will help reduce incidences of mold growth in stored seed. It is hypothesized that the hygroscopic characteristic of seeds (Srikiatden *et al.*, 2007) will facilitate the absorption of water by the superabsorbent polymers causing the reduction in seed maize moisture content.

1.2. Problem Statement

The quality of stored seed is a serious limitation to agricultural growth in many developing countries. Storage of sowing seeds without proper drying poses great problems of mold development, decay and premature germination (Hayma, 2003). On the contrary, too low moisture can cause unnecessary energy consumption and cracked seeds during the drying process and affects seed viability. Therefore, the ability to determine drying conditions that provide high quality seeds at reasonable cost is important for agriculture. Presently, the low quality of the seed maize is a significant problem facing a large number of farmers in developing countries including Kenya (CIMMYT, 1999).

After harvesting, most farmers generally maintain a proportion of their crops for sowing in the next growing season. More often greater quantities of the maize are harvested during the wet season and the seeds are susceptible to infection with mould and rapid deterioration (FAO, 1992). As a result, a large number of farmers in developing countries experience seed quality losses due to delayed or improper drying caused by the lack of knowledge and adequate drying facilities and technologies.

Commercial seed companies and gene-banks often dry relatively many small volumes of seeds. This involves drying of different samples at any one time, but it is fundamental that the seeds from different plants or plots be kept separate (Hay *et al.*, 2012). Seed drying methods employed by these seed companies such use of high temperature dryers or dehumidifier is costly to maintain and compromises the viability of the seeds. Further, use of solar dryers poses the challenge of localized high temperatures in the dryer, which leads to reduction of seed quality due to cracking of kernels and loss of viability (Uluko *et al.*, 2006).

Maize (*Zea mays* L.) is the most important cereal in Kenya and is the staple food to over 90% of the population (Jayne *et al.*, 2001). Seed maize is thus a vital input for agriculture, and seed insecurity affects subsequent production. Further, the use of poor quality seeds results to low yields and directly translates to food insecurity. Since seed security and food security are closely interfaced, it is important to maximize on ways production of high quality and viable seeds. Therefore, based on the foregoing background there is need to employ better drying methods that will ensure seed moisture content is rapidly reduced to safe storage levels. The drying methods used should also be able to maintain high seed viability.

1.3. Justification

The aim of the study was to develop an alternative and efficient method for drying seed maize to desired final moisture content using superabsorbent hydrogel under hermetic conditions while maintaining seed viability. The practicability of this method will reduce the challenge of seed maize drying during the wet season since it is not weather dependent. More also, inclusion of drying during storage enables reduce the development of mold, decay and premature germination, which cause great losses during storage. The study also aimed at developing and validating a mathematical model for hermetic drying of seed maize using super absorbent hydrogel. The model developed is useful in approximating the time reduction of product moisture content under different drying conditions (Rivzi, 2005; Wang and Brennan, 1991). It will help in decision making thus increase the drying efficiency.

The findings of the study are relevant to all parts of Kenya that grow maize. It is of benefit to seed maize breeders, commercial seed and grain companies, gene banks and agricultural research institutes. Farmers have always had to carry out drying of their harvest before selling to seed companies. This is because the high moisture levels during harvesting do not allow direct preservation of seed maize (FAO, 1992). High seed moisture also leads to development of mould and rotting of the harvested seed maize translating to losses to the farmers (Wambugu *et al.*, 2009).

The use of super absorbent hydrogels can be adopted when the weather condition is unsuitable for seed maize drying or when conditioned facilities are not available. Hydrogels rapidly bring seed moisture to safe levels. More also preserving the seed in hermetic containers using desiccants is a technology that is not dependent on a reliable power supply or expensive refrigeration and dehumidification equipment, or major modifications to buildings. Babiker *et al.*, (2010) recommended the use of desiccants such as silica gel when a limited number of seed samples are to be dried as it is cheaper compared to seed dryers. There are various anticipated advantages of using hydrogel as a desiccant in hermetic drying and storage. In hermetic drying the seeds will be free of rodent and bird attack, free from foreign matter contamination, use of low temperature, it is not weather dependent and is not labor intensive as compared to sun drying. The super absorbent hydrogel can also be recycled after it is dried.

1.4. Objectives

1.4.1. Broad Objective

To establish the feasibility of using super absorbent hydrogel in drying maize (*Zea mays L.*) seeds under hermetic conditions.

1.4.2. Specific Objectives

1. To evaluate the performance of super absorbent hydrogel in drying of seed maize under hermetic conditions.

2. To develop and validate mathematical model for the drying of seed maize using super absorbent hydrogel under hermetic conditions.
3. To evaluate the viability of seed maize dried using super absorbent hydrogel under hermetic conditions.

1.5. Hypotheses

1. The performance of super absorbent hydrogel in drying of seed maize under hermetic conditions can be evaluated.
2. Prediction models for drying of seed maize under hermetic conditions using super absorbent hydrogel can be developed and validated.
3. The viability of seed maize dried under hermetic conditions using super absorbent hydrogel can be assessed.

CHAPTER TWO

LITERATURE REVIEW

2.1. Post Harvest Challenges

Under humid and warm conditions harvested grains are susceptible to premature germination and rapid deterioration due to microbial activities. Therefore, they should be dried to safe moisture levels that inhibit the activity of microorganisms. Drying to these moisture levels is not economical for farmers in developing countries (Weinberg *et al.*, 2008). Post harvest losses in Kenya have previously been estimated at 30% of all stored produce (Wilson and Johnson, 2010). These losses occur as a result of storing harvest with high moisture content, poor hygiene and use of inappropriate storage facilities (Bett and Nguyo, 2007).

Although time of harvesting fall under pre-harvesting period, its effect has direct linkage to post harvest challenges. Delaying harvesting of maize until it is completely dry compromises seed quality as it leads to exposure to adverse conditions that alleviate deterioration (Egli, 1998). Wet weather during the harvesting period like that experienced in Kenya during the short rains of October/November 2009 results in losses that have serious impact on food security (Wilson and Johnson, 2010). The challenge of harvesting during the wet season can be reduced by use of appropriate technologies that are not weather dependent.

2.2. Methods of Drying Grain

2.2.1. Importance of Drying

Proper drying is considered one of the determining factors on whether seed maize will be effectively stored without damage. Seed maize must be adequately dried to safe moisture content to reduce survival of insects, fungus and other micro-organism build up (Jewell *et al.,* 1994; Rao *et al.,* 2006). During drying much of the grain deterioration occurs due to improper drying techniques and equipment (Salunkhe *et al*., 1985). Maize crop is usually harvested when it has reached the physiological maturity with moisture content of 25 to 42.8% (d.b) (Jewell *et al.* 1994).

The basic drying stages for seed maize includes natural drying of seeds on the cob prior to harvest, stacking harvested maize in the fields to allow them to dry further and sun drying or artificial drying of threshed seed maize (Agrawal *et al*., 1998). According to Hayma, (2003) during the field drying period, seed maize may be exposed to several undesirable elements such as insect infestation, attack by rodents and weather extremes leading to yield losses. It is therefore recommended that the seed maize be harvested and dried to safe moisture levels in a controlled environment to reduce post harvest losses. More also, it is important to store the seed maize safely away from contaminants after attaining the safe moisture content (Bishop *et al*., 1993).

Drying of seed maize to the recommended moisture content of below 15.6% dry basis increases storage life as well as maintain high quality of produce through reduction in growth of fungi, reduction of insect infestation in storage, reduction in respiration of kernels and prevention of germination while the kernels/seed retains its germination potential. The safe moisture content of 15.6% dry basis is valid for temperatures up to about 27°C while higher temperatures require lower moisture content (Hayma, 2003).

2.2.2. Conventional Drying Methods

The conventional methods that are used for drying grain in Kenya include layer drying, portable batch dryers, continuous flow dryers, sun drying and in-store drying. Layer drying refers to drying where the harvested grain is placed in a bin one layer at a time. Each layer of grain is partially dried, before the next is added, by forcing air through a perforated floor or through a duct in the bottom of the bin. To improve efficiency, the partially dried grain is stirred and mixed with the new layer. An alternative is to remove the partially dried grain and dry it completely in batches. According to FAO, (1992) one of the problems with this method of drying is finding a way to mix low-moisture grain with high-moisture grain to get the desired equilibrium in the final product. Spoilage often occurs in this attempt. Methods have been developed to detect high moisture maize in mixtures with artificially dried maize (FAO, 1992).

Portable batch dryers have a high installations cost and few maize producers, particularly small farmers, can afford to have their own (Jewell *et al.,* 1994). Portable batch dryers are useful since they can be moved from farm to farm. These dryers operate with air heated to 60 to 82°C (FAO, 1992). Continuous flow dryers on the other hand use the principle of continuous flow of grain through heated and unheated sections so that it is discharged dry and cool. Continuous flow dryers are less flexible compared to batch dryers as the equipment is the central point in grain storage depots (Ranken *et al.,* 1997).

In many tropical and sub-tropical regions, sun drying remains the preferred method of grain drying, mostly for economic reasons (Bakker-Arkema *et al.,* 1999; Agrawal *et al*., 1998). Traditional sun drying has changed little over centuries. The grain is spread on mats or paved ground in layers of 5- to 15-cm thickness and is exposed to the ambient conditions (Wilson and Johnson, 2010: Basunia and Abe, 2001; Bakker-Arkema *et al.,* 1999). Controlling sun drying is difficult due to non controlled source of energy for drying. Drying rate in open sun depends on solar radiation, ambient air temperature, ambient relative humidity, wind velocity, soil temperature, grain-layer thickness, and grain type (Jain and Tiwari, 2003).

Despite the widespread use of sun drying method in the developing countries, few controlled scientific experiments have been conducted to establish valid recommendations for every region for sun drying of seeds (Bakker-Arkema *et al.,* 1999; Mulet *et al.,* 1993). In addition, sun drying is labor intensive and exposes the seeds to contamination from dust, foreign materials, insect infestation, rodents and bird droppings (Jewell *et al.,* 1994; Golob *et al.,* 2002). With its disadvantages, it is a challenge to produce dried seeds of superior quality as they require careful handling and high hygiene standards.

In-store (or in-bin) drying is a fixed bed drying with no product movement and usually employs ambient air or slightly heated air as the drying medium (Bakker-Arkema *et al.,* 1999; Soponronnarit *et al.,* 1994). In store drying is classified into low temperature where the temperature rise is about 5^{o}C and high temperature drying of temperature above 50^{o}C (Srzednicki and Driscoll, 1994; Brooker *et al.,* 1992). The objective of in-store drying is to decrease the moisture content of the product at a rate that will prevent product deterioration. Both the minimum drying rate and the maximum final moisture content are locality-dependent; i.e. in hot and humid regions the drying rate of wet grain has to be higher, and the final moisture content lower, than in cold and dry areas (Bakker-Arkema *et al.,* 1999). Drying a bin of grain with low temperature is possible if the initial moisture content of the grain is about 25% dry basis, the average daily relative humidity of the ambient air is 50%, and the airflow rate is 2.4 m^3/m^3.minute (Brooker *et al.,* 1992; Bakker-Arkema *et al.,* 1999). The major disadvantage of high temperature drying is the over drying of the bottom product layers which requires subsequent cooling.

2.2.3. Desiccants Drying Method

Desiccant drying in a closed container is often suggested as a low-technology method to reduce the moisture content of seed germplasm (Hay *et al.*, 2012; Probert, 2003). Most of the past research encountered with regard to desiccant drying involves the use of desiccants to dry seed (Probert, 2003) as opposed to grain. The method however, is currently studied by many researchers as it has many advantages compared to traditional and other artificial seed drying methods. Desiccants such as zeolite seed drying beads® (Djaeni and Buchori, 2012; Hay *et al.*, 2012), molecular sieves (Probert, 2003), salts such as lithium chloride and calcium chloride (Probert, 2003), quick lime (Hayma, 2003), silica gel (Hay *et al.*, 2012; Ondier *et al.*, 2011; Babiker *et al.*, (2010); Rao *et al.*, 2006; Hayma, 2003; Probert, 2003; Zhanyong *et al.*, 2002; Gene bank Standards, 1994), bentonite (Sturton *et al.*, 1981) and charcoal (Probert, 2003) have been used in drying seeds for planting. The dry desiccant is used in intimate contact with or mixed with the wet seeds in an airtight container at ambient temperature (Hay *et al.*, 2012; Daniel *et al.*, 2009; Hayma, 2003; Probert, 2003). The amount of water absorbed by the desiccants depends on a number of factors such as the ratio of desiccant to seeds, temperature, and the affinity of the desiccant for water (Hay *et al.*, 2012; Probert, 2003).

Silica gel being the most commonly used desiccant absorbs vapor water, of about 35 to 40% of its dry mass, along with low regeneration temperatures of below 25^{o}C (Tahat, 2001). Dry grains of silica gel can efficiently reduce seed moisture for medium to long term storage if a ratio of 1:1 by weight is used (Rao *et al.,* 2006, Probert, 2003). Charcoal can also be used to significantly reduce seed moisture for long term storage if a ratio of 3:1 charcoal to seed ratio by weight is used (Probert, 2003). However, some types of polymers have higher water absorbent and retention properties and higher affinity towards water (Buchholz *et al,*. 1997) than the commonly used desiccants. These polymers are referred to as super absorbent polymers. They are used as soil amendments or additives for potted plants, for hygiene purposes in hospitals and sanitary industries (Buchholz *et al,*. 1997). These polymers though used as adsorbents or drying agents they have not been explored as potential desiccants in drying of agricultural produce such as seeds.

Superabsorbent polymers (SAPs), also referred to as slush powder, are polymers that can absorb and retain extremely large amounts of a liquid relative to their own mass (Horie et *al.,* 2004). Water absorbing polymers, which are classified as hydrogels when cross-linked absorb aqueous solutions through hydrogen bonding with water molecules. A SAP's ability to absorb water is a factor of the ionic concentration of the aqueous solution. In deionized and distilled water, a super absorbent polymer may absorb 500 times its weight (from 30–60 times its own volume), but when put into a 0.9% saline solution, the absorbency drops to maybe 50 times its weight (Horie et *al.,* 2004). The presence of valence cations in the solution impedes the polymers ability to bond with the water molecule.

The total absorbency and swelling capacity of SAPs are controlled by the type and degree of cross-linkers used to make the gel. Low density cross-linked SAP generally has a higher absorbent capacity and swells to a larger degree (Horie et *al.*, 2004). These types of hydrogels also have a softer and stickier gel formation. High cross-link density polymers exhibit lower absorbent capacity and swell, but the gel strength is firmer and can maintain particle shape even under modest pressure. Table 2.1 shows a sampling of super absorbent polymers of synthetic (petrochemical) origin, available from Sigma-Aldrich®, together with their morphology and absorption characteristics. Alaei *et al.* (2005) studied the absorption of A-100 with particle diameter 35 < mesh < 60 (micron) in two independent water and vapor phases and found that the amount of water absorbed by hydrogel to get to uniform gel formation is relatively equal for both water phase and vapor phase.

There are two common desiccant drying systems which include intimate mixture of the seeds and desiccant material in a sealed environment (i.e. static desiccant drying) and air circulated through separate beds of reactivated desiccant material and seed in sequence. Static desiccant drying system with an optimum ratio of seed to desiccant reduces the moisture levels rapidly within the first 2 to 3 days followed by a slow process thereafter (Hay *et al.*, 2012). The principle of drying using a desiccant is that the desiccant dries the seeds mainly by surface adsorption and capillary condensation until the two come to equilibrium (Hay *et al.*, 2012). Surface adsorption happens because the desiccant adsorbs moisture from the air thus lowering the relative humidity. The moisture diffuses from the seed due to osmotic or vapor pressure gradient. The moisture content when the desiccant and seeds are at par such that no gain or loss of moisture by both is called equilibrium moisture content (Rao *et al.*, 2006; Rivzi, 2005). In addition to maize morphology, this equilibrium moisture content of maize also depends on the temperature and humidity of ambient air as the air tight container is stored under ambient conditions (Genebank Standards, 1994).

Table 2.1: Absorbent polymers of synthetic origin available from Sigma Aldrich$^{®}$, together with morphology and absorption characteristics

Aldrich Catalog No.	Absorbent Polymer	Morphology	Absorbing characteristics
43,532-5	Poly(acrylic acid), potassium salt, lightly cross-linked	Powder; particle size 99%< 1,000mm	Absorbs *ca*. 27g/g of 1% saline solution; rate of absorption more rapid than for corresponding Na salt
43,636-4	Poly(acrylic acid), sodium salt, lightly cross-linked	Powder; particle size 99%< 1,000mm	Absorbs *ca*. 45g/g of 1% saline Solution
43,277-6	Poly(acrylic acid *co*-acrylamide), potassium salt, cross-linked	Granules; 200-1,000mm; pH 5.5.6.0	Absorbs ~300g of distilled water/g and ~27g of 1% saline solution/g.
43,278-4	Poly(acrylic acid), sodium salt-*graft*-poly(ethylene oxide), cross-linked	Granular powder; 100-850mm	Absorbs ~300g of distilled water/g and ~27g of 1% saline solution/g.
19,206-6	Poly(2-hydroxyethyl methacrylate), average Mv about 300,000	Crystals	-
18,213-3	Poly(2-hydroxypropyl methacrylate)	Crystals	-
42,427-7	Poly(isobutylene-*co*-maleic acid), sodium salt, cross linked	Fiber; 24-40mm Diameter	Absorption of 0.9 wt. % saline solution is about 65g/g; Absorption of distilled water is about 300g/g

Source: sigmaaldrich, (2013).

Using desiccant in drying of seed maize has several advantages such as energy conservation and seed quality preservation (Probert, 2003). This is because during desiccant seed drying under hermetic conditions there is little or no temperature rise as the heat of hydration is negligible. Desiccant drying thus differs from other artificial drying methods such as batch-in-bin drying which causes overheating of some seeds as the drying front moves upward from the hot air inlet. More also desiccant such as hydrogel are regenerated at relatively low temperature (Tahat, 2001) and can therefore be dried under the sun to store the energy for rainy seasons. When dry maize is exposed to humid environments, it gains moisture content and equilibrates to a value of equilibrium moisture content, which may be different than the equilibrium moisture content obtained during the moisture desorption (Rao *et al.,* 2006).

2.3. Drying Models

The hygroscopic characteristics of a seed lot describe relationships between seed moisture content and storage relative humidity at a given temperature and this can be displayed graphically by sorption isotherm curves (Sanni *et al.,* 1997). Sorption isotherm is a graph that shows the relationship between different relative humidities of the surrounding air around the seed and the equilibrium moisture content of the seed at a given temperature (Thomsen and Stubsgaard, 1998). These sorption isotherms predict moisture kinetics of seeds in confined environment (Sanni *et al.,* 1997; Kouhila *et al.,* 2001). The isotherms help to determine optimal conditions for seed drying and store environment adjustments for longevity enhancement in storage systems. Since moisture sorption isotherms vary substantially between different products or seed types, it is essential to determine sorption isotherms for each material at different conditions. Furthermore, knowledge of sorption behavior of food is useful in drying processes because it can be used to predict the optimum drying time and final moisture content of the product (Rivzi, 2005; Wang and Brennan, 1991).

Seeds usually dry or absorb moisture from its environment depending on the relative humidity of the surrounding air (Thomsen and Stubsgaard, 1998). Ambient air has an average humidity of 65-75% in Kenya and this may increase up to 90% during rainy or cloudy days. It is necessary to dehumidify the air before it is passed through to dry the grain (Atuonwu, 2013). According to Schmidt (2007) desiccants such as hydrogels dehumidifies the air, and thus increases its capacity to absorb moisture from grain. A product loses moisture (i.e. it dries out) when the relative humidity of the drying air is lower than the equilibrium relative humidity that corresponds with the moisture content of the product. The larger the difference between these two relative humidities, the faster the drying process goes (Hayma., 2003). However it is not documented how far hydogels may reduce the moisture content of atmospheric air and at what rate the reduction may proceed. This information would be useful in determining the required flow rate of the inlet air and the drying rate of the grain. The drying rate in turn controls how fast the grain dries and determines whether aflatoxin contamination will occur or not.

Drying rate is the amount of moisture removed per unit time during the drying period (Doymaz, 2006). The drying rate of seeds in a system depends on the drying rate of the individual kernels. In general, small kernels lose moisture more readily than large kernels, and naked seeds dry faster than covered seeds. Maize contains the largest kernels and dries the slowest; rice and wheat seeds are of comparable size but rice kernels are covered and therefore dry slower than wheat kernels. Grain kernels dry at a falling rate (Bakker-Arkema *et al.,* 1999).

Most commonly used drying models only consider external heat and mass transfer and neglected the heat and moisture transfer inside the product. The models explain the total moisture transport by convection and assume that during the total drying process, all heat transferred to the product is used to vaporize water. However, the internal interaction between moisture and the product must be considered. Internal transport mechanism within a single kernel is limited by its surface area and depends largely on the kernel moisture content. The use of desiccant in drying consists of constant rate and falling rate drying periods drying periods. This is because at the initial stage of drying it is mainly capillary forces (Probert, 2003) that drive free moisture to the surface of the kernel and keep it wet (Srikiatden *et al.,* 2007). External parameters i.e. air humidity and temperatures are the ones that are actively involved in the removal of moisture and this period is referred to as constant rate drying period. By keeping air humidity and temperature constant the drying rate remains constant.

As the kernel loses moisture and approaches the equilibrium moisture content, the internal resistance to moisture transport becomes greater than the external resistance. The surface starts to dry and the wet front moves into the kernel particle. From this point, the moisture movement involves both capillary flow and diffusion of water vapor (Probert, 2003). As the divide of diffusion increases then the moisture content decreases, the drying rate continuously slows down. Accordingly, this period is called the falling-rate drying period. Predicting the drying rate during the falling-rate drying period is much more complicated than during the constant-rate drying period.

Food materials (Srikiatden *et al.,* 2007) and all seeds (Probert, 2003) are classified as a hydrophilic or hygroscopic materials which losses moisture in the bound water region or sorption region. When a water potential gradient is established between the surface of the seed and its internal tissues then water in the seed begins to diffuse along the gradient. Evaporation of water from the surface of the seed depends on the water potential difference between the seed and the surrounding air (Probert, 2003). As the seed gets to equilibrium the drying rate slows down exponentially. Thus, moisture transfer in the falling rate period of drying is usually described by a diffusion model based on Fick's second law (Hougen *et al.,* 1940, Guan *et al., 2013*). Fick's second law has been used with some simplification to compute moisture diffusivity of corn (Chayjan *et al.,* 2011); fresh tilapia fillets (Guan *et al.,* 2013). For long drying period, Fick's second law can be simplified (Tutuncu and Labuza, 1996) as presented in Equation (2.1) in which MR is moisture ratio (dimensionless), D_{eff} is the effective moisture diffusivity (m^2/s) and L_0 is the half thickness of slab (m).

$$\text{InMR} = \frac{8}{\Pi^2} - \frac{\pi^2 D_{eff}\, t}{4 L_o} \tag{2.1}$$

The effective moisture diffusivity is calculated using the method of slopes where the experimental drying data in terms of ln(MR) is plotted against time and the slope is given by equation 2.2 (Hui *et al.*, 2008).

$$\text{slope} = \frac{\pi^2 D_{eff}}{4 L_o} \tag{2.2}$$

The models shown in Table 2.2 are frequently used to describe the drying phenomenon in agricultural products (Corrêa *et al.*, 2009). Moisture ratio for the models equations are defined by equation (2.3) (Erenturk *et al.*, 2004), M_i is the moisture content (% d.b) at drying time t (hours), M_e is the equilibrium moisture content (% d.b), and M_o (initial moisture content, % d.b) at $t = 0$.

Table 2.2: Mathematical models for characterizing the drying of agricultural produce

S/NO.	Model name	Model equation
1	Page	$MR = \exp(-kt^n)$
2	Two-term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$
3	Newton	$MR = \exp(-kt)$
4	Logarithmic	$MR = a\exp(-kt) + b$
5	Henderson and Pabis	$MR = a\exp(-kt)$

In the table: t is drying time (h); k is drying constant (h^{-1}); a, b, c, g, η *are* model's parameters, dimensionless. (Souce: Corrêa *et al.,* 2009).

$$MR = \frac{M_i - M_e}{M_o - M_e} \tag{2.3}$$

The mathematical model are evaluated and compared using statistical measures such as coefficient of determination (R^2), root-mean-square error (RMSE) and mean sum-of-squares of errors (MSE or χ^2). R^2 is defined as the equivalent to the ratio of the regression sum of squares (SSR) to the total sum of squares (SST), which explains the proportion of variance accounted for in the dependent variable by the model (Saeed *et al.,* 2008). It evaluates how well the model fits the data (Doungporn *et al.,* 2012; Ronoh *et al.,* 2009; Saeed *et al.,* 2008; Tabatabee *et al.,* 2004) and is usually computed using equation (2.4).

$$R^2 = \frac{SSR}{SST} \tag{2.4}$$

The RMSE is used to signify the noise in the data whiles the χ^2 shows the deviations between the experimental and calculated moisture levels (Doungporn *et al.,* 2012; Ronoh *et al.,* 2009; Tabatabee *et al.,* 2004). The RMSE and χ^2 are computed using equations (2.5) and (2.6), where MR_{exp} and MR_{pre} are the measured and predicted moisture ratios, respectively, N and z are the number of observations and constant found in the respective model, respectively (Doymaz *et al.,* 2006).

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,\,i} - MR_{exp,\,i})^2\right]^{1/2} \tag{2.5}$$

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp,\,i} - MR_{pre,\,i})^2}{N - z} \tag{2.6}$$

2.4. Seed Viability

Seeds are the basic biological inputs in crop production. It consists of parts containing the embryo which carries genetic information that can give rise to a new plant, similar in genetic and morphological characteristics (Daniel *et al.,* 2012). Therefore, the preservation of its physiological quality is very vital to healthy crop production. Seed quality depends on factors like source, time and techniques of harvesting, processing including drying and storage practices (Hayma, 2003). If the drying is too slow, there is a possibility of reduction of seed quality during the drying process due to seed ageing.

Seed viability is a measure of the percentage of seeds that are alive after storage and is best tested by germination test. Germination percentages and purity are the two factors given priority in seed certification (Owolade *et al.,* 2005). A viable seed is one which is capable of germinating when it's under suitable conditions. Seeds which fail to germinate even under optimal conditions, including treatments to remove the dormancy, are considered as non-viable seed (ISTA, 1985). The greater the viability of the seeds, the fewer the seeds will be required to make the desired number of seeds per field. International Rules for Seed Testing (ISTA, 1985) gives clearly defined procedures of a variety of seed viability testing. The criteria include a suitable substrate, adequate moisture, optimum temperature and adequate lighting. Laboratory germination test allows one to control external factors giving most uniform, rapid and complete germination. Seed germination test is done by providing the needed resources (air, water, warmth, and light) to seeds in order for them germinate.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Site

Drying studies were conducted in the Food Science Department laboratory while germination test were done in the Horticulture Department laboratories, Jomo Kenyatta University of Agriculture and Technology (JKUAT). JKUAT is located in Juja at a longitude of 37.05^{o} E, latitude 1.19^{o} S and an altitude of 1550m above sea level.

3.2. Description of the Hermetic Drying System

Figure 3.1 shows the schematic of the hermetic drying and storage system that was used in this study. The system consisted of a cylindrical air tight glass container with a lid, wire mesh basket and a stand. The glass container had capacity of 750 ml with a height of 110 mm to the neck and a base diameter of 90 mm. The container and lid had uniform thickness of 3mm and an outside diameter of 67mm. To ensure that the system was air tight a rubber seal was fitted between the container neck and the lid. The rubber seal had a diameter of 67mm and height of 15mm.

In the hermetic system, there was a cylindrical stainless steel wire mesh basket that was used to hold the seed maize. The wire basket was placed on a stainless steel stand so that the sample was not in direct contact with the hydrogel. Using hydrogel in direct contact posed the challenge of separation from the seeds. This is because as hydrogel approaches its absorption capacity it locks in moisture forming into a gel. The cylindrical wire mesh basket was fabricated from a 4 by 4 mm grid wire mesh and had a height of 90 mm and diameter of 65 mm. The baskets helped in containment of the seed maize for ease of weighing. The stands were fabricated from metal rods with height of 15 mm and 60 mm base ring diameter. Both the wire basket and base stand were fabricated at the Biomechanical and Environmental Engineering department workshop, JKUAT.

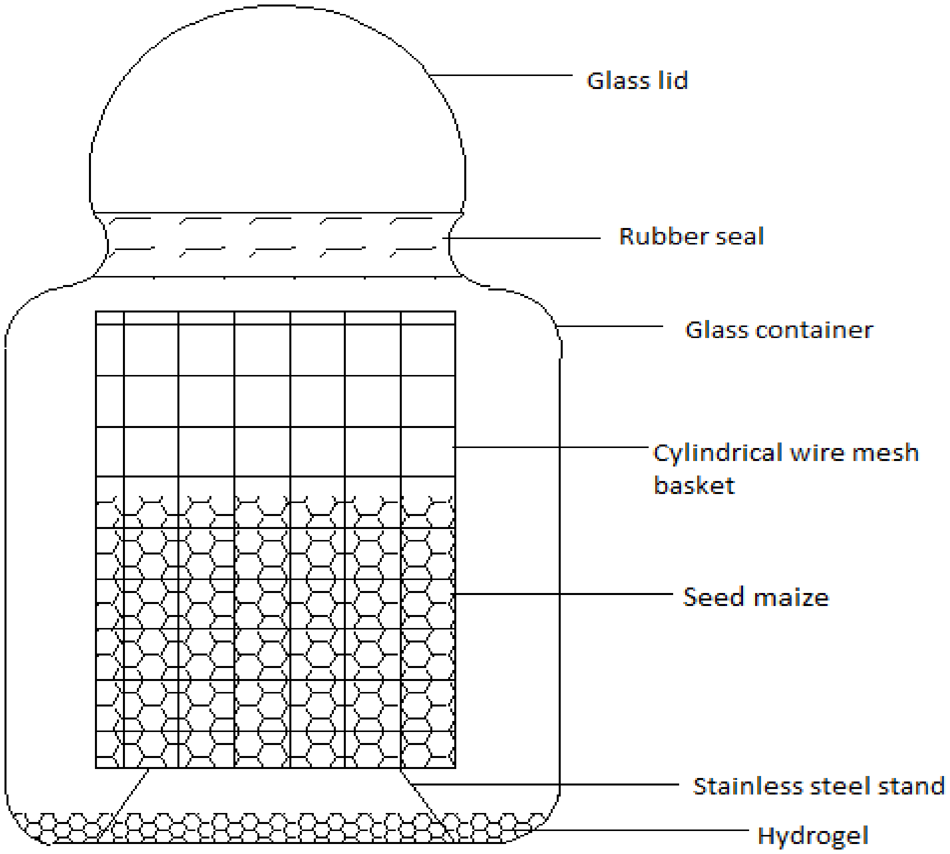

Figure 3.1: Schematic diagram of the hermetic drying and storage system that was used in this study.

3.3. Evaluating the Performance of Super Absorbent Hydrogel in Drying of Seed Maize under Hermetic Conditions

3.3.1. Research Design

The study was conducted using four drying temperature levels (25, 30, 35 and 40°C) as main plots treatments. The highest constant temperature used in the tests was 40°C as seeds should not be dried under temperature exceeding this value (Hayma, 2003). Three different initial seed moisture content levels (16, 28 and 53%, d.b) were used as sub-plots treatments. The moisture contents were selected such that they represented the minimum, intermediate and the maximum possible moisture contents during seed harvesting. Three different hydrogel to seed ratio by weight (1:5, 1:10 and 1:15), were tested in drying of seeds. The control did not utilize hydrogel. The experimental research design thus, comprised a 3 x 4 x 4 factorial experiment (Table 3.1) was used in this study. The data was collected in triplicates for each sub-sub plot (ratio of hydrogel to seed maize).

Table 3.1: Experimental research design

		Temperature			
Moisture content	Ratio	25°C	30°C	35°C	40°C
16%	0:1				
	1:5				
	1:10				
	1:15				
28%	0:1				
	1:5				
	1:10				
	1:15				
53%	0:1				
	1:5				
	1:10				
	1:15				

3.3.2. Sample Procurement and Preparation

Maize used in the study was obtained from East African Seed Company Limited, Nairobi. Unprocessed seed maize (KH 600- 15A) was obtained from East African Seed Company limited, Nairobi while super absorbent hydrogel, which is Poly-acrylic acid, sodium salt and lightly cross-linked, was purchased from Sigma Aldrich®. The procured unprocessed seed maize samples had a moisture content level lower than the desired 16, 28 and 53% (d.b) for the study. In order to raise the moisture content to the required levels of 16, 28 and 53% (d.b), the seed maize samples were reconditioned by soaking them in distilled water at 4°C for a range of 6 to 24 hours.

Soaking the seeds ensured uniform water access for uniform moisture distribution (Chemperek and Rydzak, 2006) while keeping the soaked sample at 4°C (Doungporn *et al.,* 2012; Tabatabee *et al.,* 2004) in a refrigerator helped in preventing mould growth. A colander was used to drain water from seed maize. Excess water on the surface of the seed maize was further removed using paper towels (Maskan, 2002). Once the water was completely drained from seed maize surface the seeds were left at room temperature overnight. This allowed the seeds to reach room temperature resulting in reduction of thermal stress during drying.

After reconditioning, seed maize samples were taken from different positions and depth in the container so as to ensure equal representation of moisture in the seed lot in order to determine their final moisture content (Thomsen and Stubsgaard, 1998). The samples were weighed in a drying dish of known mass using a digital meter (PB8001, Mettler Toledo, Switzerland) with a precision of ±0.01g and the wet mass recorded as W_w. The samples were then placed in a constant temperature oven set at a temperature of 105^{o}C for 24 hours. The dried seeds were removed from the oven and the dry mass recorded as W_d. The final moisture content of the seeds was then determined using equation (3.1). In order to ensure that the hydrogel was completely unhydrous before using it in drying the seed maize, it was dried in an oven at 40^{o}C to remove moisture.

3.3.3. Determination of the Drying Rate

For 25^{o}C a total of thirty six samples of 120g seed maize (12 samples for each of the three moisture contents (i.e., 16, 28 and 53%, d.b) were weighed in wire baskets of known weight using analytical mass balance (PB8001, Mettler Toledo, Switzerland) with measurement precision of ±0.01g. Based on 120g of seed maize nine samples of 24, 12 and 8g of hydrogel were weighed to attain 1:5, 1:10 and 1:15 hydrogel to seed maize ratios by weight, respectively.

The evaluation commenced by spreading the weighed samples of super absorbent hydrogel at the bottom of the hermetic system. Placing hydrogel at the bottom of the system aided in dehumidifying the system as well as absorbing the condensate that collected at the bottom of the system. Wire baskets holding the weighed seed maize were placed on the base stands inside the system and the system was completely sealed to ensure it was air tight. Each system was clearly labeled with reference to the treatment it contained. The hermetic systems were then placed in an incubator (Incubator IS62, Yamato Scientific Co., Ltd. Japan) set at $25^{o}C$ for moisture monitoring for seven days (see Figure 3.2).

Moisture content of seed maize was monitored and recorded at 3 hour intervals for the first day from 8:00 a.m to 5:00 p.m. The three hour interval helped in monitoring the moisture removal rate as most drying of biological products occurs during the falling-rate period (Srikiatden et al., 2007). Thereafter, moisture data was recorded at 12 hour intervals until no further change in moisture content was observed. The interval was increased to 12 hours because the drying rate in the second falling rate period is extremely slow (Srikiatden et al., 2007).

At any sampling time during drying the weight of the seed maize was determined and recorded as W_t. Then using initial wet mass of the seed maize W_w and initial moisture content dry basis, M_o, equation (3.2) was used to calculate the moisture content at time t, M_t. The control involved drying seed maize under similar hermetic conditions without using the super absorbent hydrogel which is equivalent to a ratio of 0:1 hydrogel to seed maize ratio by weight. This control ran concurrently with other treatment. The same procedure was repeated for other seed drying temperatures (i.e., 30, 35 and $40^{o}C$).

3.3.4. Data Analysis

The percentage initial moisture content M_o (d.b), was evaluated from equation (3.1) (Stroshine, 1998) while the moisture content at time t, M_t, during drying was determined using equation (3.2) (FAO, 2011).

$$M_o = \frac{W_w - W_d}{W_d} * 100 \qquad (3.1)$$

$$M_t = 100 - W_w\left(\frac{100 - M_o}{W_t}\right) \qquad (3.2)$$

Figure 3.2: Seed maize in hermetic systems placed in the incubator for seed moisture monitoring.

Graphs relating moisture content and time for the different treatments were plotted in order to compare their drying rate. Box plots and interaction plots were used as exploratory graphs to determine if there existed interaction between drying temperature, initial seed moisture content and ratio. Analysis of variance was also performed to determine whether or not there existed significant differences within the drying rate of the different hydrogel to seed maize ratios and also from the control. These analyses were carried out using MS Excel 2007^{TM} and R i386 3.0.2.Ink statistical computer software.

3.4. Mathematical Modeling and Validating Drying of Seed Maize using Super Absorbent Hydrogel under Hermetic Conditions

3.4.1. Data Collection Procedure

Modeling and validation of drying of seed maize using super absorbent hydrogel under hermetic conditions was done using data obtained in Section 3.2.

3.4.2. Mathematical Modeling of Drying Data

The respective moisture ratios during drying were determined using equation (2.3) and were then fitted to five (5) different mathematical models whose relations are given in Table 2.2 by non-linear regression. This was performed using MS Excel 2003^{TM} in order to select the most suitable model to describe the drying curve of seed maize drying under hermetic conditions using hydrogel. The coefficient of determination (R^2), the Chi-square (χ^2) and the root mean square error (RMSE) were used to evaluate the goodness of fit of the tested mathematical models to the measured data (Doungporn *et al.,* 2012; Ronoh *et al.,* 2009; Tabatabee *et al.,* 2004). The best model was selected based on the highest values of the R^2, the lowest values of χ^2 and RMSE (Doymaz *et al.,* 2006; Demir *et al.,* 2007; Doungporn *et al.,* 2012).

3.5. Evaluating the Viability of Seed Maize Dried using Super Absorbent Hydrogel under Hermetic Conditions

3.5.1. Data Collection Procedure

The viability of seed maize was evaluated by performing germination test to determine the maximum germination potential of the seed lot after drying using superabsorbent hydrogel under hermetic conditions for different treatments. Two hundred seeds were counted randomly for germination testing for each treatment. These seeds were divided into batches of petri dishes containing fifty seeds each. Seeds were then planted in paper substrates (filter paper) by following germination test procedure described in International Seed Testing Association (ISTA, 1985). Top of paper method was adopted and seeds are placed on top of substrate paper in glass Petri dishes with well fitting lids to prevent moisture loss. The dishes were clearly labeled and then placed in a seed germination cabinet (Koitotron, Koito industries limited Yokohama Japan) set at 25^{o}C, for monitoring. The incubator was maintained at 25^{o}C as it is the optimum temperature for seed maize germination. Figure 3.3 (a) shows preparing seed maize for germination and (b) samples in the germination chamber.

The substrates were re-moistened with equal amount of deionized water during the course of the test to provide enough moisture as required by the seeds. As seed maize germinates within seven days (ISTA, 1985) two counts were done to determine the germination percentage. The first germination count was done on the fourth day after incubating by removing the seedlings from the rest of the sample. A second count was done on the seventh day and recorded.

(a) (b)

Figure 3.3: (a) Preparing seed maize for germination testing using top of paper in petri dishes; (b) Germination samples placed in the germination chamber for monitoring.

3.5.2. Data Analysis

Germination results were expressed as a percentage of the seeds that had germinated by the end of the seventh day. Germination data was analyzed in MS Excel 2007^{TM} by plotting graphs of germination percentage against drying temperature, hydrogel to seed ratio and initial seed moisture content.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Performance Evaluation of Super Absorbent Hydrogel in Drying of Seed Maize under Hermetic Conditions

Tables 4.1-4.3 show the average final moisture contents of seed maize after hermetic drying for seven (7) days using super absorbent hydrogel with initial moisture contents of 16, 28 and 53% (d.b), respectively. The results from the three tables illustrate that increasing hydrogel to seed ratio leads to lower final moisture content. This can be attributed to the fact that increasing the amounts of hydrogel leads to reduced relative humidity in the system. This low relative humidity decreases the water potential of the air, thus, there is net water movement out of the seeds and lower final seed moisture content is attained.

Hydrogel to seed maize ratio of 1:5 by weight resulted in the least final moisture content compared to the other ratios of 0:1, 1:10 and 1:15 with the samples under the control treatment having the highest final moisture content. For example samples of 1:5 hydrogel to seed maize ratio by weight with an initial seed moisture content of 16% and dried at 25^{o}C moisture content reduced by 1.67% while those at 40^{o}C reduced by 3.99%. However, the moisture content of samples of 0:1 hydrogel to seed maize ratio and dried at 25^{o}C only reduced by 0.44% and at 40^{o}C reduced by 1.67%.

Table 4.1: Moisture content of seed maize after drying for seven days with initial moisture content of 16% (d.b)

Ratio	Temperature (^oC)			
	25	30	35	40
0:1	15.56±0.006	15.81±0.011	15.91±0.008	15.32±0.009
1:5	14.33±0.009	15.50±0.013	14.55±0.006	12.01±0.006
1:10	14.68±0.009	14.96±0.006	14.91±0.063	14.07±0.023
1:15	15.41±0.011	15.67± 0.006	15.62±0.013	14.89±0.009

*Average final moisture content ±standard error of three replications after a period of seven days

Table 4.2: Moisture content of seed maize after drying for seven days with initial moisture content of 28% (d.b)

Ratio	Temperature (^oC)			
	25	30	35	40
0:1	27.12±0.027	26.82±0.016	23.83±0.012	23.77±0.006
1:5	18.39±0.009	18.80±0.012	18.00±0.013	13.03±0.009
1:10	21.81±0.016	21.62±0.003	21.20±0.042	17.68±0.009
1:15	25.46±0.021	23.55±0.019	23.49±0.020	19.47±0.006

*Average final moisture content ±standard error of three replications after a period of seven days

Table 4.3: Moisture content of seed maize after drying for seven days with initial moisture content of 53% (d.b)

Ratio	Temperature (^oC)			
	25	30	35	40
0:1	50.86±0.023	49.69±0.126	42.21±0.016	36.66±0.018
1:5	42.83±0.015	31.66±0.011	22.91±0.029	21.88±0.009
1:10	43.83±0.034	35.37±0.018	27.18±0.014	25.20±0.011
1:15	48.87±0.043	35.99±0.018	27.21±0.033	23.34±0.009

*Average final moisture content ±standard error of three replications after a period of seven days

To explore the data and determine if an Analysis of variance (ANOVA) was suitable for data analysis, box plots were plotted as presented in Figures 4.1- 4.3. The box plot illustrated that there was distinct difference in final moisture content of seed maize for the different treatments. To further ascertain the use of ANOVA inter plots were used as presented in Figure 4.4. These plots showed that there were interactions between seed drying temperature, initial seed moisture content and ratio. The results of box plot and inter plot therefore indicated that carrying out an ANOVA was appropriate for data analysis.

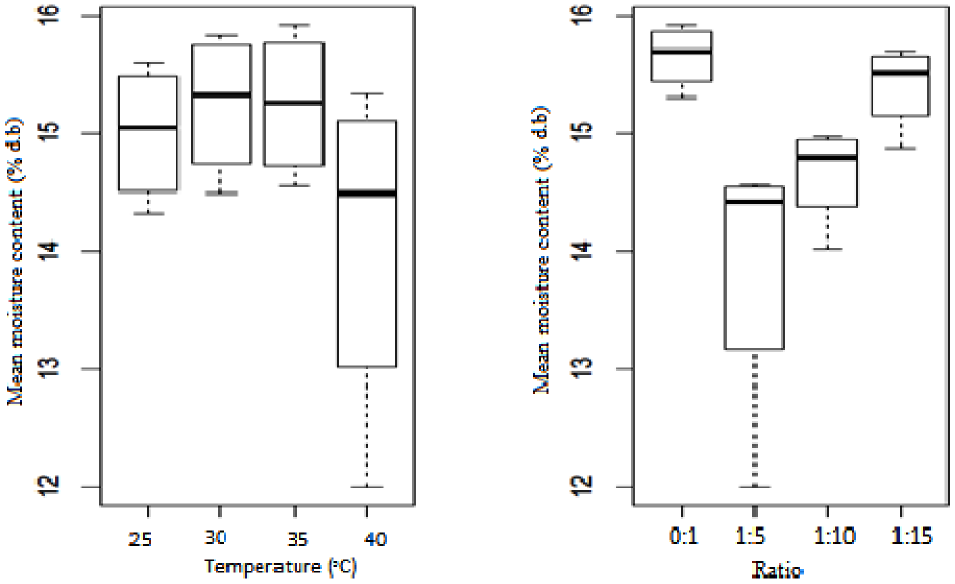

Figure 4.1: Box plots of moisture content against temperature or ratio for observed data at 16% initial moisture content (d.b).

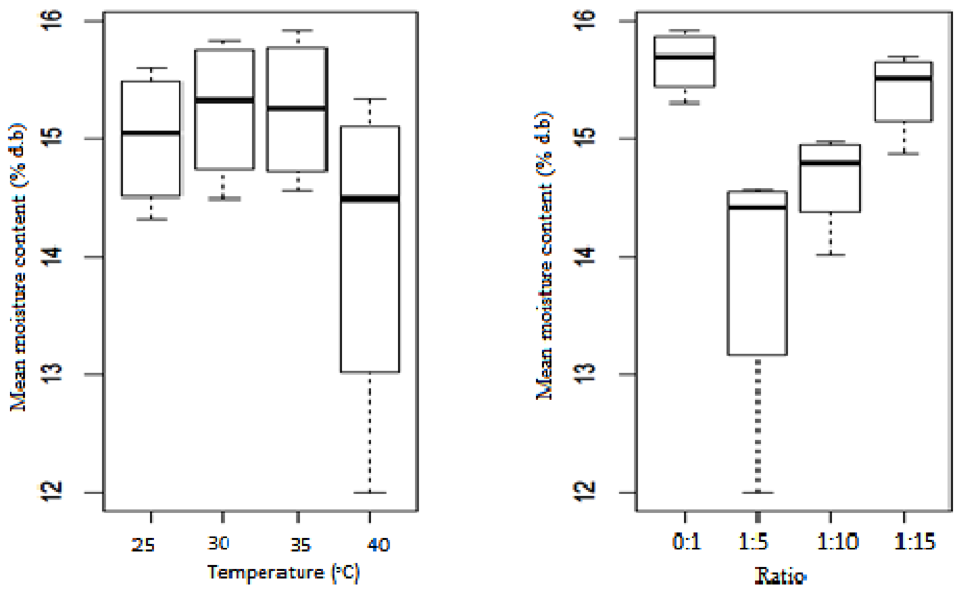

Figure 4.2: Box plots of moisture content against temperature or ratio for observed data at 28% initial moisture content (d.b).

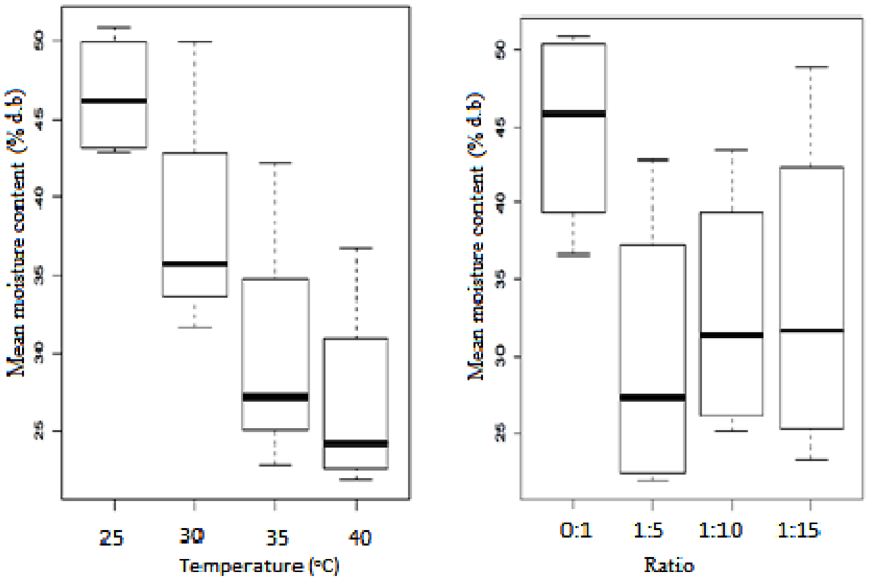

Figure 4.3: Box plots of moisture content against temperature or ratio for observed data at 16% initial moisture content (d.b).

Analysis of variance (ANOVA) for a 3x4x4 factorial was performed to test the effect of the main effects (i.e., drying temperature, initial seed moisture content and ratio) and if there was interaction between the treatments. The ANOVA results are shown in Appendix A. The results showed that at 1% significance level there were highly significant differences between the final moisture content attained for the different drying temperature, initial seed moisture content, ratio and temperature ratio interaction ($p < 0.001$). More also the final moisture content for the treatments was highly significantly different from that of control ($p < 0.001$) at 1% significance level. This implies that hydrogel ratio, initial seed moisture content and drying temperature used in drying seed maize under hermetic conditions determines the final moisture content. Similar results on desiccant drying are reported in literature (Hay *et al.*, 2012; Rao *et al.,* Daniel *et al.*, 2009; 2006; Probert, 2003). Very low final moisture content can be achieved with higher ratios and drying temperatures.

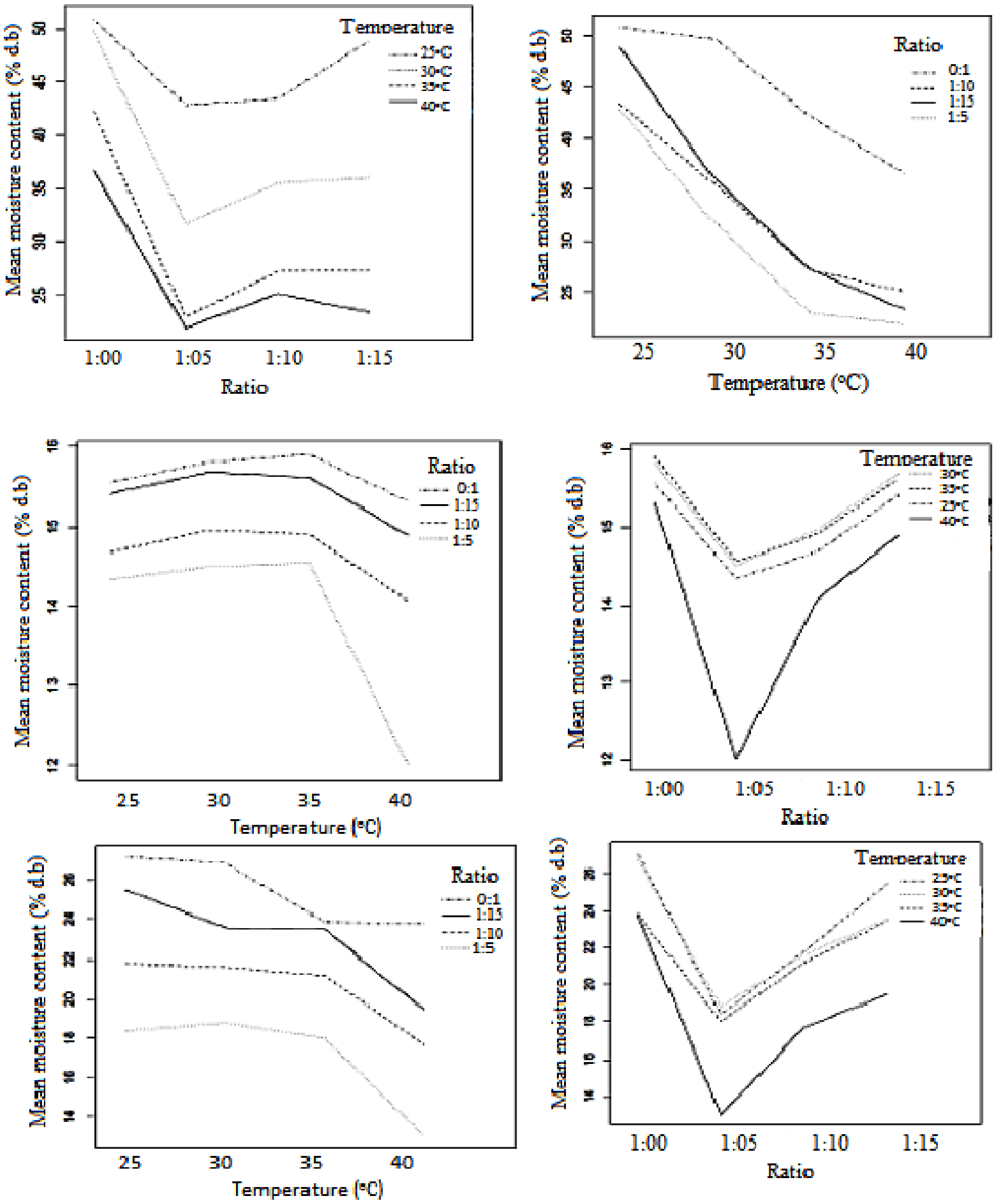

Figure 4.4: Inter-plots of mean moisture content against temperature or ratio for different initial moisture contents.

Drying curves for seed maize drying under hermetic drying conditions for 16% (d.b) initial moisture contents are shown in Figure 4.5. The influence of initial seed moisture content on seed moisture ratio is presented on Figure 4.6. The results showed that during the first 100 hours of drying there was accelerated loss of moisture as the seed maize rapidly gave up its moisture to the hydrogel. As the seed maize reached equilibrium with the hydrogel the rate of drying slowed down. This is because as the drying proceeds, there is a decrease in free water available slowing the rate of drying (Saeed *et al.*, 2008).

The influence of seed drying temperature (25, 30, 35 and 40^{o}C) on moisture ratio is shown in Figure 4.7. It was observed that higher temperature led to increased moisture removal and the final moisture content of the seed maize reduced with increase in temperature from 25, 30, 35 and 40^{o}C. These results were in agreement with findings by Djaeni and Buchori, (2012). This is attributed to water being more able to vaporize and diffuse out of the seed maize at higher temperatures as compared to lower temperatures (Saeed *et al.*, 2008, Thomsen and Stubsgaard, 1998). Moreover, increase in drying temperature increases sensible heat available for moisture removal from the seeds (Saeed *et al.*, 2008).

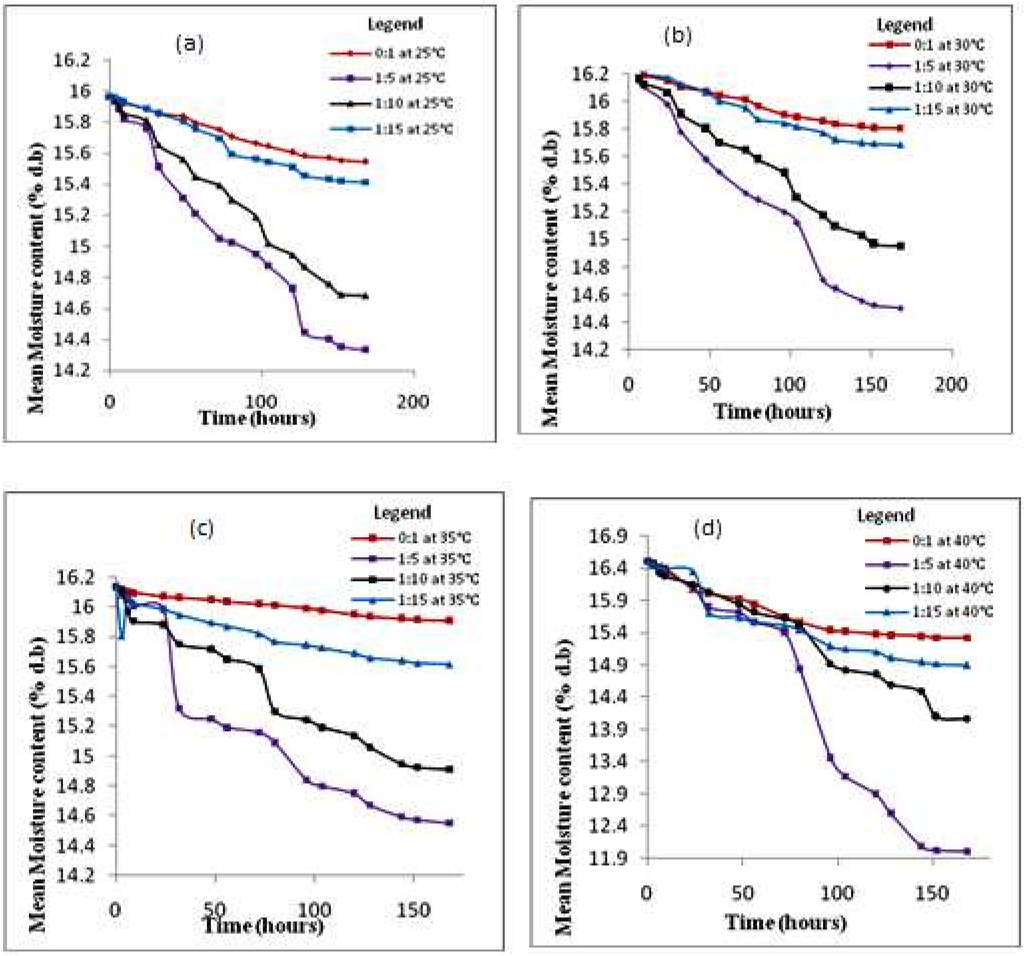

Figure 4.5: Drying curves for different hydrogel to seed maize ratios at (a) 25, (b) 30, (c) 35 and (d) 40^{o}C drying temperatures for initial seed moisture content of 16% (d.b)

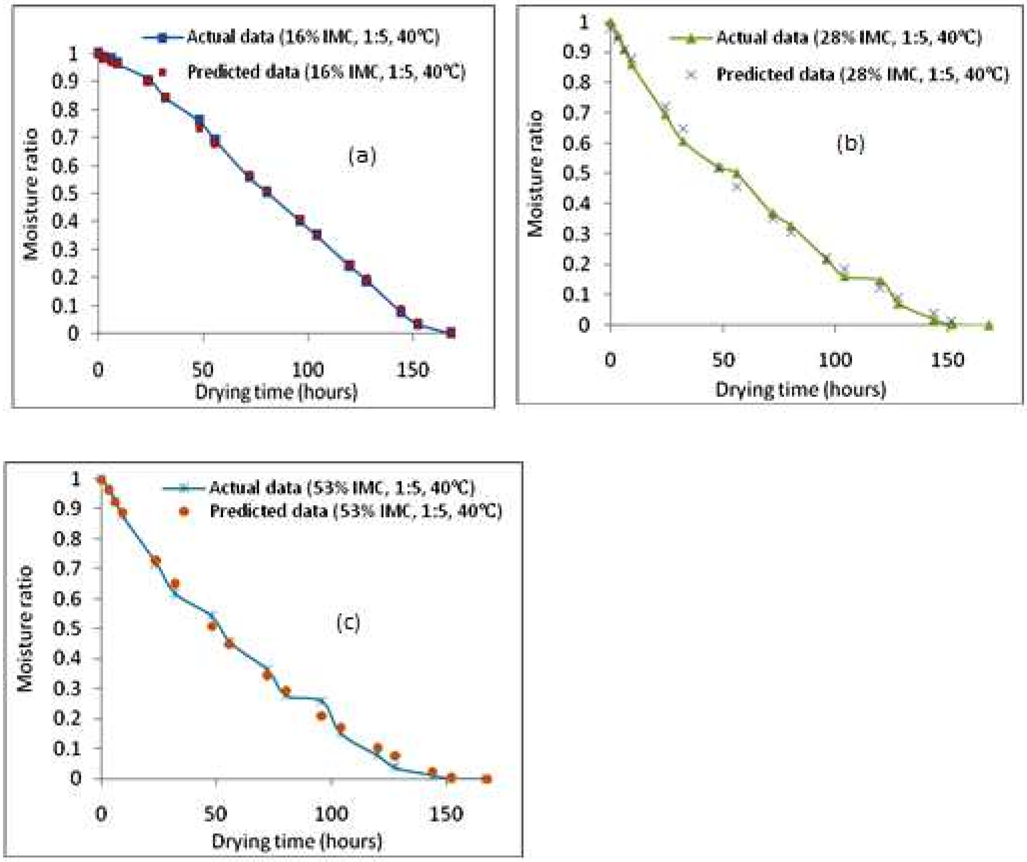

Figure 4.6: The influence of initial seed moisture content on moisture ratio using Logarithmic model for (a) 16%, (b) 28% and (c) 53%. In the figure: IMC, initial moisture content

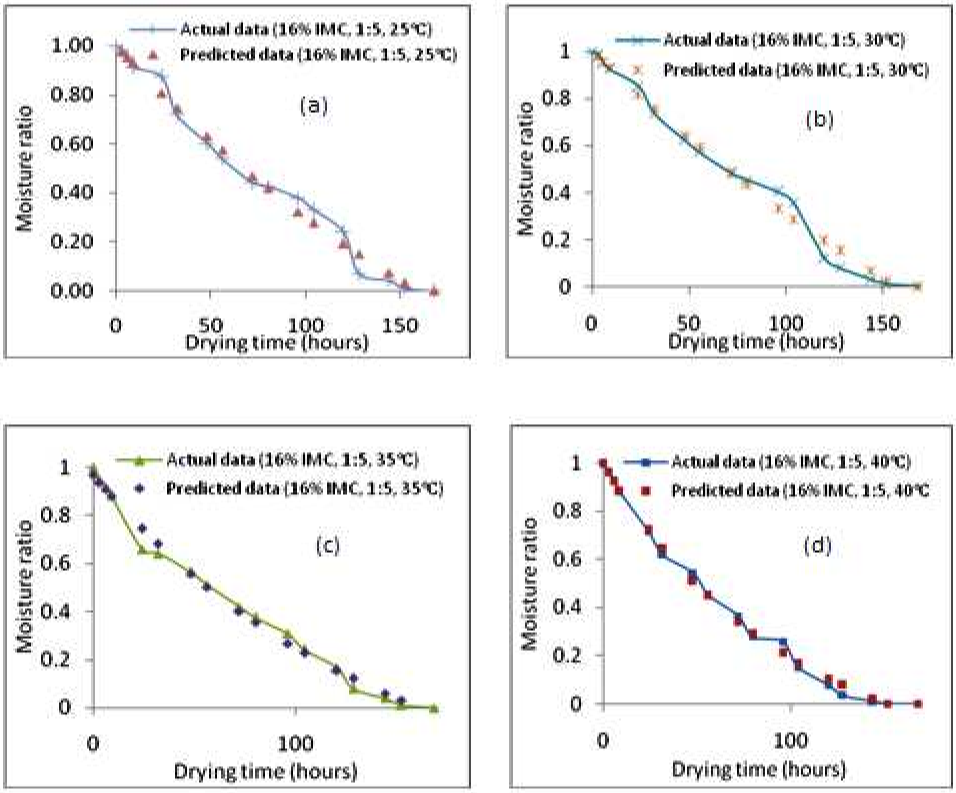

Figure 4.7: The influence of drying temperature (a) 25, (30), (35) and (d) 40^{o}C on moisture ratio using Logarithmic model. In the figure: IMC, initial moisture content

The effect of hydrogel to seed ratio on seed moisture ratio is exhibited in Figure 4.8. The results show significant moisture reduction within the first 50 hours followed by slowed drying rate. This observation is attributed to the fact that seed maize dry by moisture transfer from the seed surface to the surrounding air and then movement of moisture from inside of the seed to the surface. The low relative humidity created by the super absorbent hydrogel facilitated fast drying rate within the first 50 hours. The drying rate reduced as the hydrogel approached saturation. The least final moisture content for each set of treatment was observed for samples that were dried with 1:5

followed by those dried at 1:10, 1:15 and control respectively. Djaeni and Buchori, (2012) and Hay *et al.,* (2012) also reported that increasing the ratio of desiccant to seed led to increased moisture removal when studying zeolite seed drying beads® for drying seeds.

It was further noted that a ratio of 1:5 seed maize to hydrogel by weight dried the seeds from moisture content of 16 to 12% (d.b) after seven days. These observations are of importance as moisture content attained was below the safe storage moisture content of 15.6% (d.b) (Hayma, 2003). With periodic replacing of hydrogel the moisture content can be reduced further and in fewer days though caution must be taken as lower moisture content will force the seed into dormancy state. The results of this study have illustrated that higher ratios of hydrogel can be used to achieve fast and lower seed drying rate compared to the aforementioned desiccants in literature review.

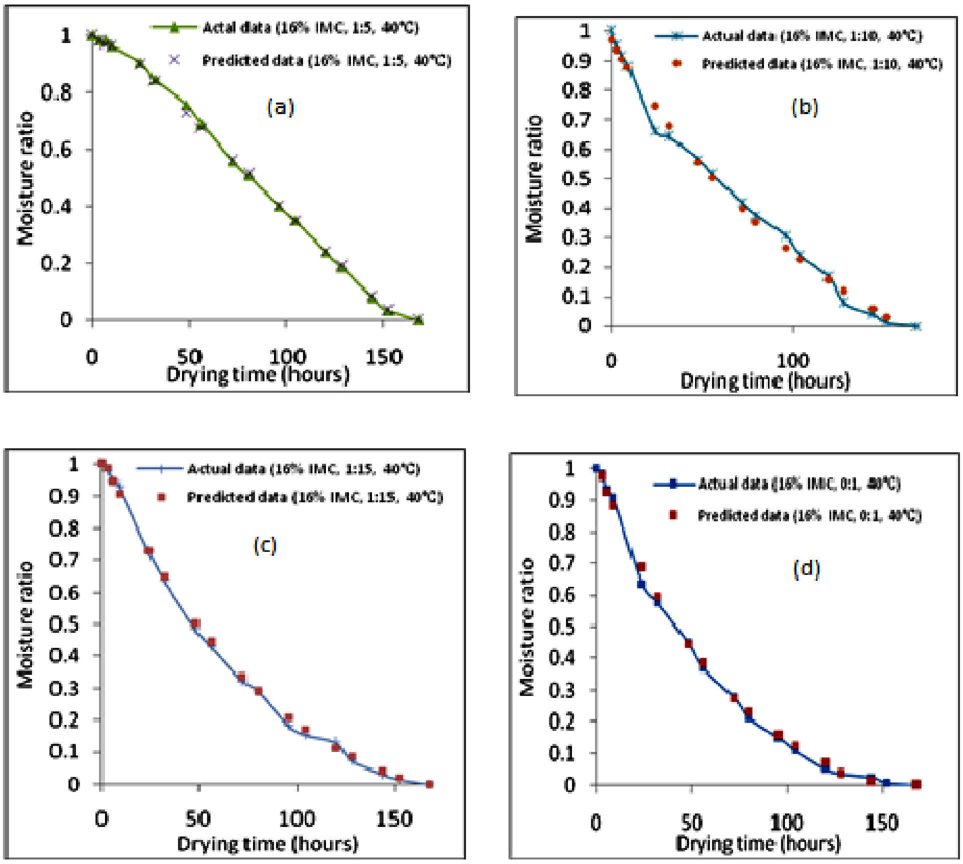

Figure 4.8: The influence of hydrogel to seed ratio (a) 1:5, (b) 1:10, (c) 1:15 and (d) 0:1 on moisture ratio using Logarithmic model. In the figure: IMC, initial moisture content

4.2. Modeling and Validating Drying of Seed Maize using Super Absorbent Hydrogel under Hermetic Conditions

The five chosen models were fitted to the measured data using non-linear regression analysis (MS Excel 2003^{TM}) based on the minimization of sum of squares by adjusting the model constants. Tables 4.4-4.7 present the established drying parameters and the performance of the models at different seed drying temperatures.

It is noticeable from the results that high values of coefficient of determination ($R^2 > 0.95$) were obtained for all the five drying models. The corresponding values of χ^2 and RMSE were in the range of (0.0016-0.0141) and (0.0400-0.3045) respectively. However, the Logarithmic model had the highest values for R^2 and the weakest values of χ^2 and RMSE. The high values of R^2 indicates how well the model fits the data (Doungporn *et al.*, 2012; Ronoh *et al.*, 2009; Saeed *et al.*, 2008; Tabatabee *et al.*, 2004). On the other hand, least values of RMSE signified less noise in the data while least values of χ^2 showed there was less deviations between the experimental and calculated moisture levels (Doungporn *et al.*, 2012; Ronoh *et al.*, 2009; Tabatabee *et al.*, 2004).

The comparison of the five models shows that Logarithmic model produced the highest values for R^2 (0.975-0.988) and the lowest values of χ^2 (0.0016-0.0036) and RMSE (0.04-0.128). The Page model had the lowest value of RMSE at 40^oC of 0.0534 as compared to 0.128 of Logarithmic model. However, comparing the values of coefficient of determination (R^2), Chi-square (χ^2) and root mean square error (RMSE), the Logarithmic model satisfactorily predicted drying of seed maize using hydrogel under hermetic conditions. The results were in agreement with previous studies conducted by Sungcome *et al.*, (2013) that showed Logarithmic model best described drying of tomato F_1 hybrid seed by desiccant material with R^2 of (0.93-0.99).

Table 4.4: Established drying parameters and performance of different models at 25^{o}C

Model	Model coefficient and constants			R^2	χ^2	RMSE
Page	k=0.0467	n=1.424		0.983	0.0026	0.0456
Two term exponential	k=0.0220	a=1	b=1	0.951	0.0084	0.1412
Newton	k=0.0126			0.951	0.0084	0.1412
Logarithmic	k=0.0002	a=6.8447		0.984	0.0021	0.0408
Henderson and Pabis	k=0.021	a=1.0351		0.952	0.0141	0.1117
			Maximum	0.984	0.0141	0.1412
			Minimum	0.951	0.0021	0.0408
			Average	0.964	0.0071	0.0961

Table 4.5: Established drying parameters and performance of different models at 30^{o}C

Model	model co-efficient and constants			R^2	χ^2	RMSE
Page	k=0.0168	n=1.0487		0.976	0.0033	0.0506
Two term exponential	k=0.0145	a=1	b=1	0.968	0.0055	0.0613
Newton	k=0.0142			0.968	0.0055	0.3046
Logarithmic	k=0.0108	a=2.2182	b=-4.2644	0.988	0.0016	0.0335
Henderson and Pabis	k=0.0135	a=1.0244		0.969	0.0045	0.1127
			Maximum	0.988	0.0055	0.3046
			Minimum	0.968	0.0016	0.0335
			Average	0.974	0.0041	0.1125

Table 4.6: Established drying parameters and performance of different models at 35^{o}C

Model	model co-efficient and constants			R^2	χ^2	RMSE
Page	k=0.0057	n=1.3336		0.976	0.0043	0.0591
Two term exponential	k=0.012	a=1	b=1	0.965	0.0054	0.0632
Newton	k=0.0138			0.965	0.0150	0.0641
Logarithmic	k=0.0068	a=1.8254	b=-0.8386	0.985	0.0019	0.0400
Henderson and Pabis	k=0.0142	a=1.0233		0.964	0.0051	0.0652
			Maximum	0.985	0.0150	0.0652
			Minimum	0.964	0.0019	0.0400
			Average	0.971	0.0063	0.0583

Table 4.7: Established drying parameters and performance of different models at 40°C

Model	model co-efficient and constants			R^2	χ^2	RMSE
Page	k=0.0038	n=1.6024		0.975	0.0040	0.0534
Two term exponential	k=0.0173	a=1	b=1	0.943	0.0105	0.0783
Newton	k=0.0143			0.942	0.0101	0.0828
Logarithmic	k=0.0157	a=5.5013	b=-4.1376	0.975	0.0036	0.1280
Henderson and Pabis	k=0.0150	a=1.0516		0.946	0.0092	0.1212
			Maximum	0.975	0.0105	0.1280
			Minimum	0.942	0.0036	0.0534
			Average	0.9563	0.0075	0.0927

The low values of χ^2 and RMSE exhibited by Logarithmic model together with results in Figure 4.9 show that there was indistinct difference between the observed and predicted moisture ratio.

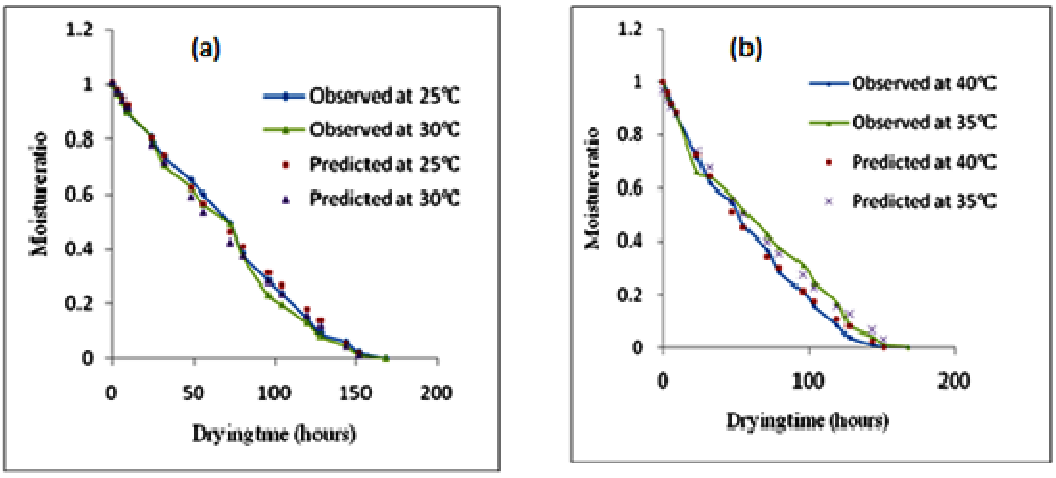

Figure 4.9: Relationship between measured and predicted moisture ratios for the Logarithmic model

4.3. Evaluation of Viability of Seed Maize Dried using Super Absorbent Hydrogel under Hermetic Conditions

Germination is defined as the clear and unobstructed emergence of the radicle, or seedling root, from the seed coat. Testing the viability of seeds by conducting seed germination test is an important way to deduce the quality of the seeds after drying. For this study seeds were considered to have germinated when the radicle emerged. The germination results are shown in Figure 4.10 and in Appendix C. These results reveal that seeds with high final moisture contents exhibited the lowest germination rates with the control recording the least germination rates. Weinberg *et al.*, 2008 also reported similar results after studying the effect of moisture level on high moisture maize under hermetic conditions.

It was established that drying temperature; hydrogel to seed ratio and initial seed moisture content affected the seed quality in terms of germination rate (Figure 4.11). Highest germination rate of 86.5% was realized with seeds dried at 40^{o}C using a ratio of 1:5 hydrogel to seed by weight and initial seed moisture content of 16%. This rate is above the accepted germination threshold of maize (70%) according to Plant Protection Act, (1976). On the other hand, lowest germination rate of 19% was realized with seeds of 53% initial moisture content with a ratio of 0:1 dried at 25^{o}C. This is because high final moisture contents in the seeds impaired germination process and stimulated microbial activities as most of these seeds were soft, swollen, and decayed, indicating that they were dead and nonviable. These observations are in agreement with those made by Owolade *et al.*, (2005).

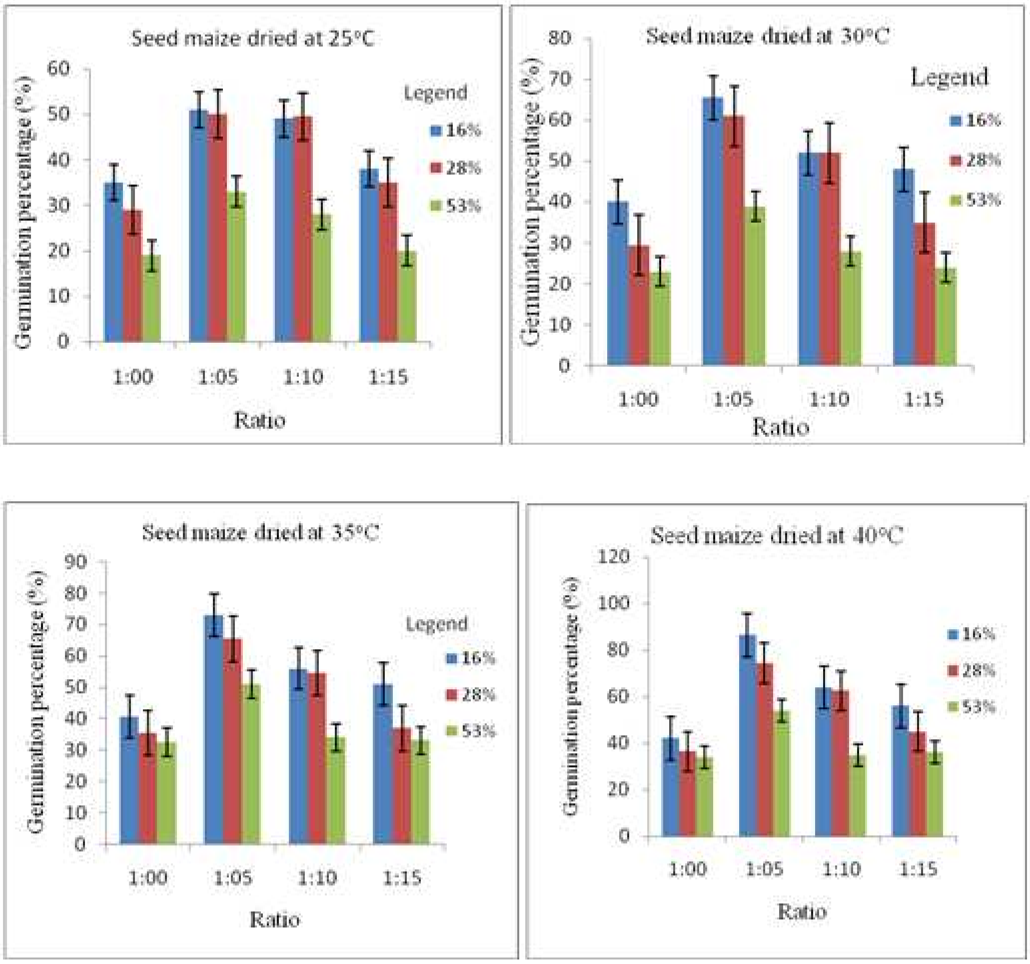

Figure 4.10: Relation between germination rates, and ratio for seed maize and seed drying temperatures.

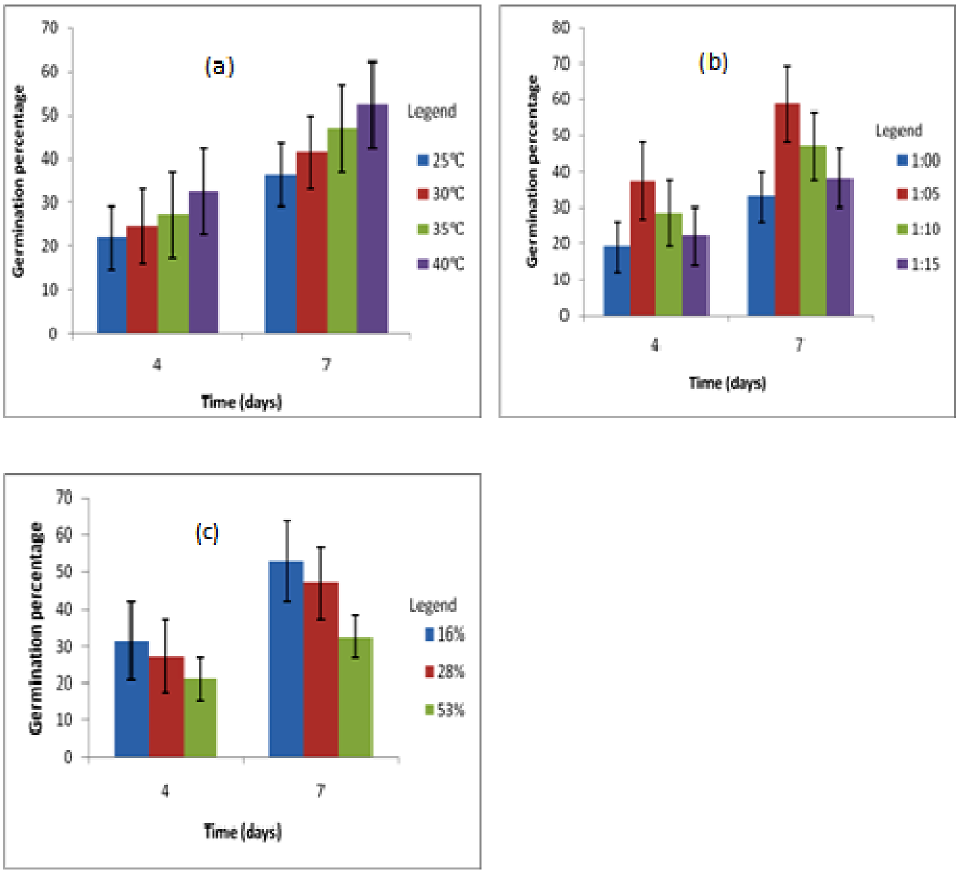

Figure 4.11: Effects of (a) drying temperature, (b) hydrogel to seed ratio and (c) initial seed moisture content on germination rate.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The specific conclusions drawn from the study were as follows:

1. The findings of this study demonstrate that hydrogel can be used as a desiccant to dry small volumes of seeds to low moisture levels recommended for gene bank storage where other drying methods such as controlled air drying are a challenge. With a ratio of 1:5 seed maize to hydrogel by weight and drying temperature of 40°C the moisture content of seed maize was reduced from 16 to 12% (d.b) after seven days of drying.
2. All the five models considered had high values of coefficient of determination ($R^2 > 0.95$) with corresponding values of χ^2 and RMSE in the range of (0.0016 - 0.0141) and (0.0400 - 0.3045), respectively. Logarithmic model was found to be the best fitted model to predict seed maize drying using hydrogel under hermetic conditions with R^2 (0.9749 - 0.9876) and the weakest values of χ^2 (0.0016 - 0.0036) and RMSE (0.04 - 0.128).
3. Seed drying using hydrogel does not alter seed viability as germination rates obtained in this study were as high as 86.5%. Lower moisture content seeds gave the highest germination percentage as opposed to high moisture seeds.

5.2. Recommendations

This study identified some key areas which require further investigation. It is therefore recommended that:

1. Extensive studies should be conducted to evaluate the economic feasibility of drying seed maize using super absorbent hydrogel under hermetic conditions with regeneration of the hydrogel. This will help determine further the financial viability and sustainability of its use in large scale by gene banks and seed companies.
2. Logarithmic model should be adopted in developing standardized tables for determining the optimum hydrogel to seed ratios for drying seed maize under hermetic conditions.
3. Further investigation to be performed on improving the drying efficiency of hydrogel in order to attain germination percentages above the set germination standards.

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APPENDICES

Appendix A: ANOVA Results

Appendix A.1: Analysis of variance table for all effects and interactions at 16% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
Temperature	3	11.1783	3.7261	8767.3	< 2.2e-16	141.108	***
Ratio	3	23.6899	7.8966	18580.3	< 2.2e-16	13.902	***
Temperature: Ratio	9	5.7822	0.6425	1511.7	< 2.2e-16	4.298	***
Residuals	32	0.0136	0.0004				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.2: Analysis of variance table for single effects at 16% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
Temperature	3	11.1783	3.7261	26.359	1.158e-09		***
Ratio	3	23.6899	7.8966	55.861	1.541e-14	6.562	***
Residuals	41	5.7958	0.1414				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.3: Analysis of variance table for interactions at 16% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
temperature:ratio	15	40.650	2.71003	6376.5	< 2.2e-16	3.662	***
Residuals	32	0.014	0.00042				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.4: Analysis of variance table for all effects and interactions at 28% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
Temperature	3	160.95	53.652	282.046	< 2.2e-16	141.108	***
Ratio	3	455.75	151.917	798.624	< 2.2e-16	13.902	***
Temperature: ratio	9	26.63	2.958	15.552	2.341e-09	4.298	***
Residuals	32	6.09	0.190				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.5: Analysis of variance table for single effects at 28% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Fc	
Temperature	3	160.95	53.652	67.243	6.999e-16		***
Ratio	3	455.75	151.917	190.402	< 2.2e-16		***
Residuals	41	32.71	0.798				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.6: Analysis of variance table for interactions at 28% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
Temperature:Ratio	15	643.33	42.889	225.47	< 2.2e-16	3.662	***
Residuals	32	6.09	0.190				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.7: Analysis of variance table for effects and interactions at 53% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
Temperature	3	2833.68	944.56	254142.0	< 2.2e-16	141.108	***
Ratio	3	1556.85	518.95	139628.0	< 2.2e-16	13.902	***
Temperature:Ratio	9	201.71	22.41	6030.1	< 2.2e-16	4.298	***
Residuals	32	0.12	0.00				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.8: Analysis of variance table for single effects at 53% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
Temperature	3	2833.68	944.56	191.88	< 2.2e-16	141.108	***
Ratio	3	1556.85	518.95	105.42	< 2.2e-16	6.562	***
Residuals	41	201.83	4.92				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix A.9: Analysis of variance table for interactions at 53% moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	F_c	
Temperature:Ratio	15	4592.2	306.149	82372	< 2.2e-16	3.753	***
Residuals	32	0.1	0.004				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix B: Model Parameters and Measures of Goodness of Fit

Appendix B.1: Statistical parameters and measure from modeling of drying curves: Page model

Temp. (^oC)	Ratio	Initial moisture content (%)	Constants		R^2	χ^2	RMSE
	Page model		K	n			
25	0:1	16	0.000592	1.614996	0.9883	0.001557	0.040000
25	1:5	16	0.001721	1.440350	0.9768	0.00314	0.054073
25	1:10	16	0.000575	1.663163	0.9839	0.002504	0.047001
25	1:15	16	0.000320	1.825213	0.9932	0.001172	0.032163
25	0:1	28	8.06E-5	2.086251	0.9819	0.003343	0.050149
25	1:5	28	0.032953	0.930502	0.9972	0.000384	0.018404
25	1:10	28	0.492470	0.819850	0.9885	0.001389	0.035014
25	1:15	28	0.000563	1.609734	0.9479	0.006652	0.076610
25	0:1	53	0.001553	1.450499	0.9899	0.004228	0.061075
25	1:5	53	0.016010	1.011016	0.9741	0.003463	0.055280
25	1:10	53	0.0131411	1.019920	0.9849	0.001807	0.039929
25	1:15	53	0.000591	1.615383	0.9883	0.001557	0.037064
30	0:1	16	0.004240	1.238779	0.964	0.004808	0.061075
30	1:5	16	0.005553	1.251194	0.9671	0.004931	0.065963
30	1:10	16	0.001906	1.43305	0.966	0.005211	0.067810
30	1:15	16	0.008867	1.12520	0.983	0.002387	0.045894
30	0:1	28	0.042692	0.839382	0.9919	0.000977	0.029357
30	1:5	28	0.030565	0.900316	0.9935	0.000816	0.026825
30	1:10	28	0.049188	0.81888	0.9878	0.001473	0.036051
30	1:15	28	0.001235	1.528823	0.9868	0.002387	0.044648
30	0:1	53	0.0040421	1.218085	0.9269	0.0086320	0.087271
30	1:5	53	0.012642	1.106402	0.9772	0.003395	0.054731
30	1:10	53	0.026600	0.067083	0.9927	0.001017	0.029961
30	1:15	53	0.013484	1.056901	0.9731	0.003746	0.057493
35	0:1	16	0.0042388	1.238823	0.964	0.004808	0.065134
35	1:5	16	0.0055553	1.251195	0.9671	0.004931	0.070000
35	1:10	16	0.0019099	1.432580	0.966	0.005211	0.067810
35	1:15	16	0.0088673	1.125206	0.983	0.002387	0.050000
35	0:1	28	0.010225	1.028781	0.9384	0.006952	0.078323
35	1:5	28	0.005449	1.85799	0.9714	0.00361	0.056439
35	1:10	28	0.010000	1.000000	0.996	0.012946	0.106879
35	1:15	28	0.000159	1.94802	0.9872	0.002395	0.045966
35	0:1	53	0.000591	1.615383	0.9883	0.001557	0.037064
35	1:5	53	0.007002	1.161254	0.9779	0.002981	0.051334
35	1:10	53	0.007146	1.18191	0.9873	0.001864	0.040556
35	1:15	53	0.007628	1.162528	0.9873	0.001833	0.040211

40	0:1	16	0.006143	1.262365	0.9907	0.001462	0.035911
40	1:5	16	4.37E-6	2.695352	0.9824	0.003268	0.053696
40	1:10	16	7.53E-6	2.77752	0.9461	0.0082234	0.0852336
40	1:15	16	0.004691	1.286387	0.9721	0.004227	0.061073
40	0:1	28	0.000172	1.436944	0.9875	0.002407	0.046086
40	1:5	28	0.000877	1.557923	0.9726	0.003837	0.058188
40	1:10	28	0.0145951	1.113804	0.9937	0.000916	0.028432
40	1:15	28	0.001695	1.533431	0.9983	0.000292	0.016057
40	0:1	53	0.005883	1.207014	0.9749	0.003607	0.056417
40	1:5	53	0.008138	1.266183	0.9891	0.001709	0.038827
40	1:10	53	0.002408	1.405215	0.9844	0.0023860	0.045888
40	1:15	53	0.000533	1.686341	0.9055	0.015067	0.115303
		Ave.	0.0043325	1.352148	0.9774	0.0035386	0.0521806
		Max.	0.0145951	2.77752	0.9983	0.015067	0.115303
		Min.	0.000172	0.067083	0.9055	0.000292	0.016057

Appendix B.2: Statistical parameters and measure from modeling of drying curves: Two term exponential

Temp. (^oC)	Ratio	Initial moisture content (%)	Constants			R^2	χ^2	RMSE
Two term exponential			K	A	b			
25	0:1	16	0.012652	1	1	0.9626	0.007465	0.081156
25	1:5	16	0.01	1	1	0.9619	0.007119	0.079255
25	1:10	16	0.01	1	1	0.9519	0.009135	0.089778
25	1:15	16	0.01	1	1	0.956	0.010809	0.097662
25	0:1	28	0.1115	1	1	0.9209	0.015788	0.118029
25	1:5	28	0.025195	1	1	0.9962	0.000541	0.021847
25	1:10	28	0.024145	1	1	0.9853	0.002565	0.047513
25	1:15	28	0.00938	1	1	0.909	0.011400	0.099029
25	0:1	53	0.011796	1	1	0.9522	0.007786	0.082888
25	1:5	53	0.016786	1	1	0.9739	0.003467	0.055306
25	1:10	53	0.015623	1	1	0.9846	0.0018818	0.040050
25	1:15	53	0.007477	1	1	0.8527	0.022601	0.141210
30	0:1	16	0.01354	1	1	0.9693	0.006298	0.074544
30	1:5	16	0.012181	1	1	0.9528	0.009197	0.090085
30	1:10	16	0.011673	1	1	0.9521	0.0092730	0.090453
30	1:15	16	0.012694	1	1	0.9597	0.010575	0.096598
30	0:1	28	0.022464	1	1	0.988	0.001958	0.041566
30	1:5	28	0.020344	1	1	0.9918	0.001168	0.032108
30	1:10	28	0.023985	1	1	0.9847	0.002661	0.048445
30	1:15	28	0.012944	1	1	0.9616	0.006755	0.077205
30	0:1	53	0.010915	1	1	0.915	0.009388	0.091013
30	1:5	53	0.019672	1	1	0.9765	0.003699	0.057129
30	1:10	53	0.0023341	1	1	0.9924	0.001052	0.030464
30	1:15	53	0.0107203	1	1	0.9726	0.003834	0.005816

35	0:1	16	0.012375	1	1	0.9526	0.005842	0.071794
35	1:5	16	0.016185	1	1	0.9638	0.006519	0.075843
35	1:10	16	0.013096	1	1	0.9445	0.008152	0.084814
35	1:15	16	0.015282	1	1	0.9797	0.002752	0.049277
35	0:1	28	0.011635	1	1	0.9386	0.006976	0.078453
35	1:5	28	0.012472	1	1	0.9688	0.004448	0.062644
35	1:10	28	0.013859	1	1	0.9877	0.002585	0.047761
35	1:15	28	0.0011431	1	1	0.9336	0.012829	0.106394
35	0:1	53	0.014244	1	1	0.9702	0.006157	0.073668
35	1:5	53	0.014223	1	1	0.9746	0.003608	0.056420
35	1:10	53	0.01569	1	1	0.9838	0.002654	0.004839
35	1:15	53	0.01543	1	1	0.9838	0.002647	0.046658
40	0:1	16	0.018402	1	1	0.9874	0.003025	0.005167
40	1:5	16	0.010092	1	1	0.8816	0.02663	0.051663
40	1:10	16	0.007877	1	1	0.8277	0.023162	0.153288
40	1:15	16	0.01593	1	1	0.9681	0.006233	0.042958
40	0:1	28	0.01166	1	1	0.9347	0.012654	0.074159
40	1:5	28	0.011	1	1	0.9495	0.008844	0.105667
40	1:10	28	0.023371	1	1	0.9933	0.001233	0.088338
40	1:15	28	0.016304	1	1	0.9839	0.005306	0.068421
40	0:1	53	0.014596	1	1	0.9686	0.004515	0.063117
40	1:5	53	0.01614	1	1	0.9836	0.003303	0.053985
40	1:10	53	0.05076	1	1	0.9681	0.010806	0.097644
40	1:15	53	0.011968	1	1	0.8678	0.020715	0.135195
		Ave.	0.0167032	1	1	0.9567	0.0074586	0.0705691
		Max.	0.1115	1	1	0.9962	0.02663	0.153288
		Min.	0.0011431	1	1	0.8277	0.000541	0.0048391

Appendix B.3: Statistical parameters and measure from modeling of drying curves: Newton model

Temp. (°C)	Ratio	Initial moisture content (%)	Constants	R^2	χ^2	RMSE
Newton			K			
25	0:1	16	0.012652	0.9626	0.007465	0.051156
25	1:5	16	0.01	0.9619	0.007119	0.079255
25	1:10	16	0.01	0.9519	0.009135	0.089778
25	1:15	16	0.01	0.956	0.010809	0.097662
25	0:1	28	0.01115	0.9209	0.015788	0.118029
25	1:5	28	0.02519	0.9962	0.000541	0.021847
25	1:10	28	0.0124145	0.9853	0.002565	0.047573
25	1:15	28	0.00938	0.909	0.011114	0.099029
25	0:1	53	0.011796	0.9522	0.007786	0.082888
25	1:5	53	0.016786	0.9739	0.003467	0.055300
25	1:10	53	0.014623	0.9846	0.001818	0.040050
25	1:15	53	0.007477	0.8527	0.022601	0.141217

30	0:1	16	0.01354	0.9693	0.006298	0.074544
30	1:5	16	0.012181	0.9528	0.009197	0.0090085
30	1:10	16	0.011673	0.9521	0.009273	0.090453
30	1:15	16	0.012694	0.9597	0.010575	0.096598
30	0:1	28	0.0022464	0.988	0.001958	0.041566
30	1:5	28	0.020344	0.9918	0.001168	0.032108
30	1:10	28	0.023341	0.9847	0.002661	0.048453
30	1:15	28	0.017203	0.9616	0.006755	0.077205
30	0:1	53	0.012375	0.915	0.009388	0.091013
30	1:5	53	0.016185	0.9765	0.003699	0.057129
30	1:10	53	0.013096	0.9924	0.001052	0.30464
30	1:15	53	0.015282	0.9726	0.003834	0.058161
35	0:1	16	0.011635	0.9526	0.005842	0.071794
35	1:5	16	0.016185	0.9638	0.006519	0.075843
35	1:10	16	0.013096	0.9445	0.008152	0.049277
35	1:15	16	0.015282	0.9797	0.002752	0.078453
35	0:1	28	0.011635	0.9386	0.006976	0.062644
35	1:5	28	0.012472	0.9688	0.004448	0.047761
35	1:10	28	0.013859	0.9877	0.002585	0.106394
35	1:15	28	0.011431	0.9336	0.12829	0.073668
35	0:1	53	0.014244	0.9702	0.006157	0.05642
35	1:5	53	0.014223	0.9746	0.003608	0.048391
35	1:10	53	0.01569	0.9838	0.002654	0.046658
35	1:15	53	0.01543	0.9838	0.002467	0.051663
40	0:1	16	0.018402	0.9874	0.003025	0.153288
40	1:5	16	0.010092	0.8816	0.02663	0.142958
40	1:10	16	0.007877	0.8277	0.023162	0.074159
40	1:15	16	0.01593	0.9681	0.006233	0.105667
40	0:1	28	0.01166	0.9347	0.012654	0.088338
40	1:5	28	0.011	0.9495	0.008844	0.032987
40	1:10	28	0.023371	0.9933	0.001233	0.068421
40	1:15	28	0.016304	0.9839	0.005303	0.063117
40	0:1	53	0.014596	0.9686	0.004515	0.053985
40	1:5	53	0.01614	0.9836	0.003303	0.070224
40	1:10	53	0.014196	0.9723	0.005589	0.131950
40	1:15	53	0.011968	0.8678	0.020715	0.008687
		Ave.	0.0137156	0.9567	0.009744	0.0764044
		Max.	0.02519	0.9962	0.12829	0.304640
		Min.	0.0022464	0.8277	0.000541	0.008687

Appendix B.4 Statistical parameters and measure from modeling of drying curves: Logarithmic model

Temp. (°C)	Ratio	Initial moisture content (%)	Constants			R^2	χ^2	RMSE
Logarithmic model			K	A	b			

25	0:1	16	0.004234	2.076012	-1.0707	0.9922	0.001111	0.031308
25	1:5	16	0	2.049545	-1.04557	0.9875	0.001719	0.0389443
25	1:10	16	0	3.67	-2.66296	0.993	0.000965	0.029183
25	1:15	16	0	2.20	-1.17042	0.9864	0.002101	0.043059
25	0:1	28	0.001219	5.920586	-4.89541	0.9779	0.003321	0.054135
25	1:5	28	0.024716	0.981961	0.000687	0.9963	0.000484	0.020559
25	1:10	28	0.021337	0.934867	0.00687	0.9866	0.001546	0.036939
25	1:15	28	0.000268	21.47767	-0.0103	0.9768	0.002593	0.047832
25	0:1	53	0.002627	2.868488	-20.4952	0.9874	0.001664	0.038314
25	1:5	53	0.00975	1.18345	-1.88153	0.9886	0.001378	0.034872
25	1:10	53	0.0109	1.101623	-0.25481	0.9888	0.001293	0.03379
25	1:15	53	0.000157	37.67205	-0.13487	0.9402	0.007334	0.080444
30	0:1	16	0.005806	1.695335	-36.5995	0.993	0.001006	0.029797
30	1:5	16	0.003219	2.525756	-0.68991	0.9868	0.001883	0.040767
30	1:10	16	0.002308	3.301033	-1.52941	0.9912	0.001227	
30	1:15	16	0.004553	2.07125	-2.29434	0.9881	0.001863	0.032910
30	0:1	28	0.021783	0.939943	-1.03299	0.9880	0.001402	0.040545
30	1:5	28	0.01927	0.973323	0.10934	0.9920	0.000969	0.035766
30	1:10	28	0.020942	0.935818	-0.0059	0.9863	0.001585	0.029235
30	1:15	28	0.004274	2.030703	-0.01368	0.9928	0.000986	0.0327402
30	0:1	53	0.000659	8.847981	-1.0416	0.9720	0.003006	0.025489
30	1:5	53	0.014899	1.106446	-7.91889	0.9822	0.002537	0.051502
30	1:10	53	0.02072	1.007166	-0.1217	0.9937	0.000836	0.047310
30	1:15	53	0.010686	1.183558	-0.03399	0.9848	0.002000	0.0027414
35	0:1	16	0.002509	2.80885	-0.22927	0.9904	0.001120	0.042011
35	1:5	16	0.012236	1.188788	-1.87207	0.9684	0.004708	0.031440
35	1:10	16	0.003816	2.14597	-0.16385	0.9787	0.002811	0.064453
35	1:15	16	0.008607	1.275705	-1.18248	0.9944	0.000700	0.049803
35	0:1	28	0.004961	1.616959	-0.31904	0.9514	0.005443	0.024856
35	1:5	28	0.005997	1.639222	-0.65428	0.9854	0.001806	0.069300
35	1:10	28	0.00881	1.302341	-0.65696	0.9965	0.000466	0.039915
35	1:15	28	0.001659	4.4442	-0.29231	0.9819	0.002631	0.020283
35	0:1	53	0.006929	1.539562	-3.43081	0.9896	0.001527	0.048185
35	1:5	53	0.007077	1.420402	-0.53213	0.9916	0.0001066	0.036710
35	1:10	53	0.009592	1.25714	-0.45298	0.9957	0.000581	0.030663
35	1:15	53	0.009165	1.26615	-0.27672	0.9965	0.000458	0.022638
40	0:1	16	0.14337	1.157704	-0.29316	0.9920	0.001209	0.201040
40	1:5	16	0.000529	13.35695	-0.13561	0.9532	0.007703	0.032656
40	1:10	16	0.000188	30.45606	-12.2905	0.9198	0.009616	0.082444
40	1:15	16	0.011878	1.210726	-29.4215	0.9731	0.004050	0.921112
40	0:1	28	0.002089	3.644147	-0.17915	0.9817	0.002680	0.059778
40	1:5	28	0.00168	4.185412	-2.63121	0.9912	0.001171	0.048627
40	1:10	28	0.002297	1.048342	-3.18378	0.9935	0.000944	0.032144
40	1:15	28	0.0011438	1.280695	-0.02972	0.992	0.001288	0.028865
40	0:1	53	0.006677	1.480874	-0.23304	0.9905	0.001238	0.033711
40	1:5	53	0.010079	1.271621	-0.52162	0.9954	0.000653	0.033057
40	1:10	53	0.007451	1.46709	-0.27396	0.9890	0.001600	0.024008
40	1:15	53	0.001273	5.455523	-0.45828	0.9269	0.010618	0.037567

	Ave.	0.0098821	4.097396	-3.010442	0.9827	0.0022903	0.0701062
	Max.	0.14337	37.67205	0.10934	0.9965	0.010618	0.921112
	Min.	0.0	0.934867	-36.5995	0.9198	0.0001066	0.0027414

Appendix B.5 Statistical parameters and measure from modeling of drying curves: Henderson and Pabis model

Temp. (°C)	Ratio	Initial moisture content (%)	Constants		R^2	χ^2	RMSE
Henderson and Pabis			K	A			
25	0:1	16	0.013417	1.056567	0.9576	0.006634	0.076501
25	1:5	16	0.01	1.06	0.9575	0.006309	0.074609
25	1:10	16	0.01	1.06	0.9458	0.008095	0.084576
25	1:15	16	0.01	1.09	0.9482	0.008828	0.088256
25	0:1	28	0.12051	1.077405	0.9122	0.014143	0.111709
25	1:5	28	0.024661	0.982415	0.9963	0.000484	0.020661
25	1:10	28	0.0022052	0.927714	0.9865	0.001560	0.037106
25	1:15	28	0.009677	1.025272	0.9061	0.010930	0.098204
25	0:1	53	0.011693	1.004117	0.9384	0.006971	0.078428
25	1:5	53	0.012853	1.026691	0.9671	0.004265	0.061346
25	1:10	53	0.014501	1.042213	0.9855	0.002147	0.043523
25	1:15	53	0.012281	1.068547	0.9264	0.011554	0.100968
30	0:1	16	0.0150341	1.052861	0.9663	0.005462	0.694200
30	1:5	16	0.014354	1.00842	0.9741	0.003590	0.056283
30	1:10	16	0.015942	1.015047	0.9829	0.002600	0.047900
30	1:15	16	0.015134	0.991077	0.9803	0.002733	0.049105
30	0:1	28	0.0011693	1.004117	0.9384	0.006971	0.078428
30	1:5	28	0.012853	1.026691	0.9671	0.004265	0.061346
30	1:10	28	0.014501	1.042213	0.9855	0.002147	0.0435523
30	1:15	28	0.012281	1.068547	0.9264	0.011554	0.100968
30	0:1	53	0.015034	1.052861	0.9663	0.005462	0.069420
30	1:5	53	0.014354	1.00842	0.9741	0.003590	0.056283
30	1:10	53	0.015942	1.015047	0.9829	0.002600	0.047900
30	1:15	53	0.01557	1.007696	0.9834	0.002453	0.046524
35	0:1	16	0.0122460	0.99076	0.9534	0.005819	0.071656
35	1:5	16	0.017066	1.057084	0.9617	0.005918	0.072260
35	1:10	16	0.013309	1.015111	0.9431	0.008094	0.084507
35	1:15	16	0.0151340	0.991077	0.9803	0.002733	0.049105
35	0:1	28	0.011693	1.004117	0.9384	0.006971	0.078428
35	1:5	28	0.012853	1.026691	0.9671	0.004265	0.061346
35	1:10	28	0.014501	1.042213	0.9855	0.002147	0.043523
35	1:15	28	0.012281	1.068547	0.9264	0.011554	0.100968
35	0:1	53	0.015034	1.052861	0.9663	0.005462	0.069420
35	1:5	53	0.014354	1.00842	0.9741	0.003590	0.056283
35	1:10	53	0.015942	1.015047	0.9829	0.002600	0.047900

35	1:15	53	0.015557	1.007696	0.9834	0.002453	0.046524
40	0:1	16	0.019295	1.046786	0.9853	0.002544	0.047376
40	1:5	16	0.011335	1.111842	0.9580	0.023066	0.142660
40	1:10	16	0.008454	1.0546652	0.8200	0.022244	0.140097
40	1:15	16	0.016928	1.059069	0.9656	0.005423	0.069174
40	0:1	28	0.012494	1.066553	0.9277	0.011459	0.100555
40	1:5	28	0.01174	1.058855	0.9440	0.007904	0.083510
40	1:10	28	0.024103	1.02818	0.9929	0.001079	0.030858
40	1:15	28	0.017612	1.079577	0.9794	0.003882	0.058148
40	0:1	53	0.014638	1.002668	0.9684	0.004573	0.063105
40	1:5	53	0.016696	1.032997	0.9815	0.003048	0.518610
40	1:10	53	0.014951	1.050379	0.9687	0.004963	0.066174
40	1:15	53	0.012318	1.027051	0.8648	0.020578	0.134551
		Ave.	0.015927	1.033587	0.9578	0.006410	0.093011
		Max.	0.12051	1.111842	0.9963	0.023066	0.694200
		Min.	0.0011693	0.927714	0.8200	0.000484	0.020661

Appendix C: Germination Results

Appendix C.1: The germination data of seeds dried at 25

viability testing for seeds dried at 25^{o}C						
Moisture content	Ratio	Number of seeds	Day 4	Day 7	Total Germinated	Germination rate (%)
16%	0:1	200	36	34	70	35.0
	1:5	200	66	36	102	51.0
	1:10	200	62	36	98	49.0
	1:15	200	46	30	76	38.0
28%	0:1	200	30	28	58	29.0
	1:5	200	61	39	100	50.0
	1:10	200	61	38	99	49.5
	1:15	200	36	34	70	35.0
53%	0:1	200	28	10	38	19.0
	1:5	200	44	22	66	33.0
	1:10	200	32	24	56	28.0
	1:15	200	26	14	40	20.0

Appendix C.2: The germination data of seeds dried at 30^{o}C

Viability testing for seeds dried at 30^{o}C						
Moisture content	Ratio	Number of seeds	Day 4	Day 7	Total Germinated	Germination rate (%)
16%	0:1	200	38	42	80	40.0
	1:5	200	88	43	131	65.5
	1:10	200	68	36	104	52.0
	1:15	200	52	44	96	48.0
28%	0:1	200	33	26	59	29.5
	1:5	200	76	46	122	61.0
	1:10	200	60	44	104	52.0
	1:15	200	37	33	70	35.0
53%	0:1	200	30	16	46	23.0
	1:5	200	50	28	78	39.0
	1:10	200	32	24	56	28.0
	1:15	200	29	19	48	24.0

Appendix C.3: The germination data of seeds dried at 35°C

Viability testing for seeds dried at 35°C						
Moisture content	Ratio	Number of seeds	Day 4	Day 7	Total Germinated	Germination rate (%)
16%	0:1	200	42	39	81	40.5
	1:5	200	90	56	146	73.0
	1:10	200	64	48	112	56.0
	1:15	200	56	46	102	51.0
28%	0:1	200	40	31	71	35.5
	1:5	200	74	57	131	65.5
	1:10	200	59	50	109	54.5
	1:15	200	43	31	74	37.0
53%	0:1	200	41	24	65	32.5
	1:5	200	68	34	102	51.0
	1:10	200	40	28	68	34.0
	1:15	200	43	23	66	33.0

Appendix C.4: The germination data of seeds dried at 40°C

Viability testing for seeds dried at 40°C						
Moisture content	Ratio	Number of seeds	Day 4	Day 7	Total Germinated	Germination rate (%)
16%	0:1	200	47	37	84	42.0
	1:5	200	111	62	173	86.5
	1:10	200	83	45	128	64.0
	1:15	200	63	49	112	56.0
28%	0:1	200	44	29	73	36.5
	1:5	200	89	60	149	74.5
	1:10	200	76	49	125	62.5
	1:15	200	56	34	90	45.0
53%	0:1	200	48	20	68	34.0
	1:5	200	77	31	108	54.0
	1:10	200	44	26	70	35.0
	1:15	200	42	30	72	36.0