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

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Abstract—The aim of this study was to establish the feasibility of using super absorbent hydrogel in drying of maize (Zea mays L.) seeds under hermetic conditions to offer alternative solutions to seed drying. The performance of hydrogel in drying seed maize under hermetic conditions 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 temperatures of 40, 35, 30 and 25°C and initial moisture content of 16, 28 and 53% (dry basis). The control did not utilize any hydrogel. Analysis of variance for a 4*4*3 factorial experiment was computed to ascertain whether drying temperature and hydrogel to seed ratio had any effect on the final moisture content attained and if there was any interaction between the ratio and drying temperature. The results revealed that the effects of temperature, ratio and combination of temperature and ratio on the final moisture content were highly significant (p < .001). The study demonstrates that super absorbent hydrogel is a potential desiccant that can be used in drying seed maize under hermetic conditions.

Keywords—seed maize, hydrogel, desiccant, hermetic drying

I. INTRODUCTION

Maize (Zea mays L.) is the most important cereal in Kenya and is the staple food to over 90% of the population [1]. According to a baseline survey carried out in Siaya and Busia Districts of Western Kenya[1], 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%).

Additional studies conducted in Kenya to establish the state of seed maize storage facility [2], 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 ingestion into the facility by use of barriers such as aluminum lining, silica gel and insulation by use of plastic foam have been made [2].

There are various drying methods practiced widely in the world today among them sun drying, forced air drying, modified solar drying [3] and desiccant drying [4], [5]. 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 [3]. 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 [3]. 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°C [6].

Desiccant drying in a closed container is often suggested as a low-technology method to reduce the moisture content of seed germplasm [4], [5]. Most of the past research encountered with regard to desiccant drying involves the use of desiccants to dry seed [5] as opposed to grain. Desiccant such as zeolite seed drying beads® [4], molecular sieves [5], salts such as lithium chloride and calcium chloride [5] quick lime [6] and silica gel [4], [7], [6], [5] have been used in drying seeds for planting. The desiccant is used in intimate contact with or mixed with the seed in airtight container [4], [8], [6], [5]. 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 [4], [5].

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°C [9]. 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 [7], [5]. 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 [5]. However, some types of polymers have higher water absorbent and retention properties and higher affinity towards water [10] than the commonly used desiccants. These polymers are referred to as super absorbent polymers or hydrogels. Therefore, based on the foregoing background this study was conducted to evaluate the feasibility of using super absorbent hydrogel in drying seed maize under hermetic conditions.
II. MATERIALS AND METHODS

A. Experimental set up

Fig. 1 shows the schematic of the hermetic drying and storage system that was used in this study. The system consisted of an air tight glass container with lid, wire mesh basket and a stand. The air tight glass container cylindrical in nature fitted with a lid will form the hermetic system and was purchased from glass ware supplier for use in this study. This air tight 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 were made of glass that had uniform thickness of 3 mm. The container lid had an outside diameter of 67 mm. 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 67 mm and height of 15 mm. In the hermetic system there was a cylindrical stainless steel wire mesh basket that was used to hold the grains and a stainless steel stand where it was placed. The cylindrical wire mesh basket was fabricated from a 4 mm by 4 mm hole opening wire mesh and had a height of 90 mm and diameter of 65 mm. The baskets helped in containment of the seed for easy weighing. The stands were fabricated from rods with height of 15 mm and 60 mm base ring diameter. Both the wire basket and base stand were fabricated at Biomechanical and Environmental Engineering department workshop, Jomo Kenyatta University of Agriculture and Technology.

![Fig. 1 Schematic of the hermetic drying and storage system.](image)

B. Sample preparation

The materials required for this study include unprocessed seed maize and super absorbent hydrogel. The seed maize (KH 600-15A) was obtained from East African Seed Company limited, Nairobi while the super absorbent hydrogel, which is Poly - acrylic acid, sodium salt and lightly cross-linked, was purchased from Sigma Aldrich	extsuperscript{®}. The hydrogel was dried in an oven at 40°C to remove moisture before using it in drying the seed maize.

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 the initial moisture content, \([11]\). The samples were weighed in a drying dish of known mass and the wet mass recorded as \(W_w\). The samples were then placed in a constant temperature oven set at a temperature of 105°C for 24 hours. The dried grains were removed from the oven and the dry weight recorded as \(W_d\). The percentage initial moisture content dry basis \(M_o\), was evaluated from equation (1) \([12]\).

\[
M_o = \frac{W_w - W_d}{W_d} \times 100
\]

(1)

To raise the moisture content to the required moisture content of 16, 28 and 53% (dry basis), samples of seed maize were soaked in distilled water at 4°C for a range of 6 to 24 hours. Soaking ensured uniform water access to seed maize for uniform moisture distribution \([13]\) and keeping the soaked sample at 4°C \([14]\) 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 \([15]\). The final moisture content of the grain was then determined using equation (1).

C. Data collection Procedure

Three treatments consisting of 1:05, 1:10 and 1:15 hydrogel to seed maize ratio by weight under different temperatures of 25, 30, 35 and 40°C, and moisture content of 16, 28 and 53% (dry basis) were used to evaluate the performance of the super absorbent hydrogel in drying seed maize. A control that did not utilize hydrogel was also used. The highest constant temperature used in the tests was 40°C as seeds (planting materials) should not be dried under temperature exceeding this value \([6]\). The moisture contents were selected such that they represented the minimum, intermediate and the maximum possible moisture contents during seed harvesting. Heterogeneity of the data was observed by conducting the batch experiment at constant temperatures and same initial moisture content for each respective set. For the 25°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% dry basis) were weighed in wire baskets of known weight using analytical mass balance (Toledo PB8001) 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 1:05, 1:10 and 1:15 hydrogel to seed maize ratios by weight, respectively.

The weighed samples of super absorbent hydrogel were spread at the bottom of the hermetic system. Spreading 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 (Yamato incubator IS62) set at the 25°C for moisture monitoring for seven days.

Moisture content of seed maize was monitored and recorded at 3 hour intervals for the first day. The three hour interval helped in monitoring the moisture removal rate as most drying of biological products occurs during the falling-
rate period [16]. 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 [16]. At any sampling time during drying the weight of the seed maize was determined and recorded as \(W_2\). Then using initial weight of the seed maize \(W_i\) and initial moisture content (dry basis), \(M_i\), equation (2) [17], was used to calculate the moisture content at time \(t\), \(M_t\):

\[
M_t = 100 - W_t \left( \frac{100 - M_i}{W_2} \right)
\] (2)

Control involved drying seed maize under similar hermetic conditions without using the super absorbent hydrogel which is equivalent to a ratio of 1:0 hydrogel to seed maize ratio by weight. This control ran concurrently with other treatments. The same procedure was repeated for other temperatures, (i.e., 30, 35 and 40°C).

D. Data processing and analysis

Data collected was used to plot graphs relating moisture content and time for the different temperatures and hydrogel seed maize ratios in order to compare the drying rate for the different ratios and temperatures. An Analysis of Variance was performed to determine whether or not there exist significant differences in the final moisture content with the drying temperatures, ratios and combinations of temperature and ratio.

III. RESULTS AND DISCUSSION

Table I, II and III shows 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 show that increasing hydrogel seed ratio leads to lower final moisture content. A ratio of 1:05 resulted in the least final moisture content compared to 1:0, 1:10 and 1:15. For example, the moisture content of samples of 1:05 hydrogel to seed maize ratio with an initial moisture content of 16% and dried at 25°C reduced by 1.67% while those at 40°C reduced by 3.99%. However, the moisture content of samples of 1:0 hydrogel to seed maize ratio and dried at 25°C reduced by 0.44% and at 40°C reduced by 1.67%.

Analysis of variance for a 4*4*3 factorial was performed to test the influence of the main effects (i.e., temperature and ratio) and if there was interaction between temperature and the ratio. The results show highly significant differences between the final moisture content attained for the drying temperature, ratio and temperature ratio combination \((p < .001)\). Thus, the ratio of hydrogel to seed and drying temperature used in drying seeds under hermetic conditions determines the final moisture content of the seed. Similar results on desiccant drying are reported in literature [4], [7], [8], [5]. Very low final moisture content can be achieved with higher ratios and drying temperatures.

### Table I

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00</td>
<td>15.56±0.011</td>
</tr>
<tr>
<td>1:05</td>
<td>14.33±0.015</td>
</tr>
<tr>
<td>1:10</td>
<td>14.68±0.015</td>
</tr>
<tr>
<td>1:15</td>
<td>15.41±0.019</td>
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*Average final moisture content ± standard deviation of three replications after a period of seven days

### Table II

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00</td>
<td>27.12±0.047</td>
</tr>
<tr>
<td>1:05</td>
<td>18.39±0.016</td>
</tr>
<tr>
<td>1:10</td>
<td>21.81±0.027</td>
</tr>
<tr>
<td>1:15</td>
<td>25.46±0.038</td>
</tr>
</tbody>
</table>

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

### Table III

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Temperature (°C)</th>
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<tbody>
<tr>
<td>1:00</td>
<td>50.86±0.041</td>
</tr>
<tr>
<td>1:05</td>
<td>42.83±0.026</td>
</tr>
<tr>
<td>1:10</td>
<td>43.83±0.059</td>
</tr>
<tr>
<td>1:15</td>
<td>48.87±0.074</td>
</tr>
</tbody>
</table>

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

Drying curves for seed maize under hermetic drying conditions at respective constant temperature and moisture content presented in Fig. 2 to 4. The results showed that 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 [18]. Final moisture content of the seed maize reduced with increase in temperature from 25, 30, 35 and 40°C. This was as a result of water being more able to vaporize and diffuse out of the seed maize at higher temperatures as compared to lower temperatures [18], [11]. It is a fact that lower moisture content is achieved with a higher drying temperature and ratios as revealed in Fig. 2 to 4.
of Science and Technology and Jomo Kenyatta University of Agriculture and Technology. The authors further extend their gratitude to East African Seed Company for their supply of seed maize used in this study.

REFERENCES


IV. CONCLUSIONS

This study was conducted to evaluate the performance of super absorbent hydrogel in drying of seed maize under hermetic conditions. The results show that the drying rate is affected by ratio of hydrogel and drying temperature. Super absorbent hydrogel can be used as a desiccant to dry seed maize under hermetic conditions. Very low final moisture content can be achieved with higher ratios and drying temperature. Drying at lower temperatures would require higher ratios in order to reduce the moisture content to safe storage levels.

Use of hydrogel as a desiccant to dry small volumes of seeds can be practically feasible to use where other drying methods such as controlled air drying are a challenge. However, to speed up the drying rates and achieve lower final moisture content the hydrogel should be replaced periodically.

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