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Effect of Initial Moisture Content of Maize Grain on Moisture Removal Rate and Energy Used in Experimental Vertical Pneumatic Dryer

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Abstract: Maize is a staple food and source of income in Kenya. However, postharvest losses are estimated at 12% to 20% of the national total output primarily due to high moisture storage. Drying to safe level of 13.5% before storage is essential. One of the main factors which influence drying process is initial moisture content (MC) of the grain. Therefore, this paper presents the effect of initial MC of maize grain on moisture removal rate (MRR) and energy used in drying. The experiments were based on selected initial MC levels of 20%, 25% and 30%, wet basis (wb). The first experiment involved loading experimental vertical pneumatic dryer with 70.0 kg of wet maize grain with initial MC of 20%. The grain was then dried for 2 hours as MRR and energy used monitored at an interval of 15 minutes. The grain and drying air mass flow rate was controlled at 771 kg/h and 547 kg/h, respectively. The plenum chamber air temperature was maintained at 70°C using proportional integral derivative controller. The maize grain variety used was hybrid 614 sourced from a farmer in Njoro sub-County, Nakuru County, Kenya. Similar experiments were repeated but using maize grain with initial MC of 25% and 30%, wb. The MC of 20%, 25% and 30% were obtained by rewetting maize grain with initial MC of 11.4% (wb) in tap water at a temperature of 18°C for 0.75 hours, 1.75 hours and 5.75 hours, respectively. The MRR results ranged from 0.0914 kg/kg.h to 0.0357 kg/kg.h for maize grain with initial MC of 20%, 0.1043 kg/kg.h to 0.0556 kg/kg.h for 25% and 0.1185 kg/kg.h to 0.0705 kg/kg.h for 30%. The energy used for air heating (E_a) for each level of MC was 10.5 kWh. The energy used for grain transportation (E_g) was 4.6 kWh for MC of 20%, 4.8 kWh for 25% and 5.0 kWh for 30%. Data analysis results showed that the initial MC of the maize grain had significant effect ($P < 0.05$) on MRR. However, the effect of initial MC on E_a and E_g was not significant ($P > 0.05$).

Keywords: Initial Moisture Content, Maize Grain, Moisture Removal Rate, Energy Used in Drying, Pneumatic Dryer

1. Introduction

Maize is a predominant staple food crop in Kenya and Sub-Saharan Africa [1-4]. It is the third most valuable cereal grain worldwide after wheat and rice [5]. The major source of calories and income for many households across the world is derived from maize [4, 6].

The world maize production is approximately at 10.14 billion metric tonnes [7, 8]. Africa produces about 7% of the total world maize output with Eastern and Southern Africa regions leading [9, 10]. In Kenya, annual maize production is estimated at 3 million tonnes while consumption is about 88 kg per capita per year [4, 11, 12].

In sub-Saharan Africa, it estimated that 5% to 45% of maize grain weight losses are attributed to pest infestation [13-15]. In Kenya, the postharvest losses of maize grain are about 12% to 20% of the total national production [16]. The major causes of the postharvest losses are mainly due to excessive grain moisture content, physical environmental conditions and biological agents such as insect pests and mould [17].

Maize is usually harvested when the moisture content is in the range of 21.9% and 31.6% [18]. This implies that drying is essential to reduce the moisture to the recommended level of 13.5% for safe storage [19]. Drying is a crucial process because it prevents mould damage and aflatoxin contamination which make the product unfit for human and livestock consumption [20]. It also reduces losses due to respiration, insects and pests infestation [21, 22]. In addition, it improves shelf life and quality of the product [23].

Despite significance of drying in agriculture and other sectors, it is energy intensive process [24, 25]. It is estimated that energy used in the drying process is 60% of the energy cost in maize production [26, 27].

Open sun drying (OSD) is commonly used method for maize grain in many tropical and sub-tropical regions mainly for economic reasons [28, 29]. However, it is labour intensive, heavily rely on solar radiation, ambient air temperature, relative humidity, air velocity, soil temperature, grain layer thickness and grain type [30]. In addition, OSD is unsustainable due to diminishing availability of open spaces for drying due to increasing population, inadequate temperature control hence overheating of the grain and exposure of the product to contamination by dust, foreign materials, insect infestation, animals, rodents and bird droppings [31, 32].

The use of mechanized maize grain dryers (MGDs) has improved drying efficiency and product quality compared with OSD. Nevertheless, these dryers consume more energy since drying and transportation of the product are separated processes hence high drying cost [33]. Further, MGDs are bulk, inadequate and susceptible to mechanical breakdown due to increased number of moving parts hence high maintenance cost. Therefore, there is need to explore other technologies that provide solutions to the existing challenges in maize grain drying. An applicable technology is pneumatic drying in which the grain is continuously dried while being transported in vertical duct by the heated airstream [34].

The main parameters affecting grain drying include air temperature, air flow rate and relative humidity [35]. In addition, initial moisture content of the product is also one of the factors which affect grain drying [36, 37].

However, there is knowledge gap on how the initial moisture content (MC) of maize grain influence moisture removal rate (MRR) and energy used in drying. Thus, this paper aimed at determining the effect of initial MC of maize grain on MRR and energy used (i.e. Energy for air heating and grain transportation) in experimental vertical pneumatic dryer (PGD).

2. Materials and Methods

2.1. Experimental Vertical Pneumatic Maize Dryer Used

Figure 1 and Figure 2 show schematic and actual experimental vertical pneumatic maize grain dryer used, respectively. The dryer was developed and tested in the Department of Agricultural Engineering at Egerton University, Njoro Campus, Nakuru County, Kenya.

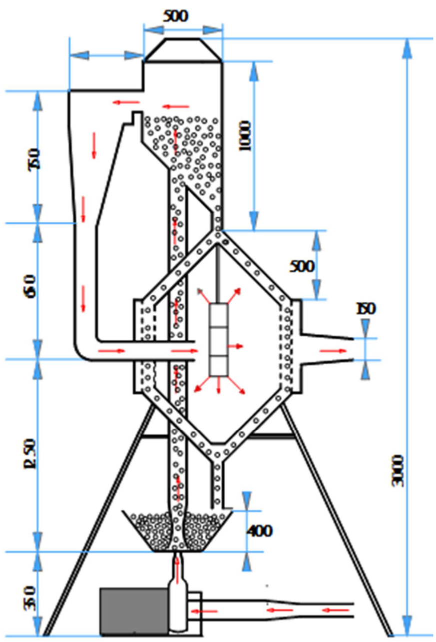

Figure 1. *Schematic experimental vertical pneumatic maize grain dryer.*

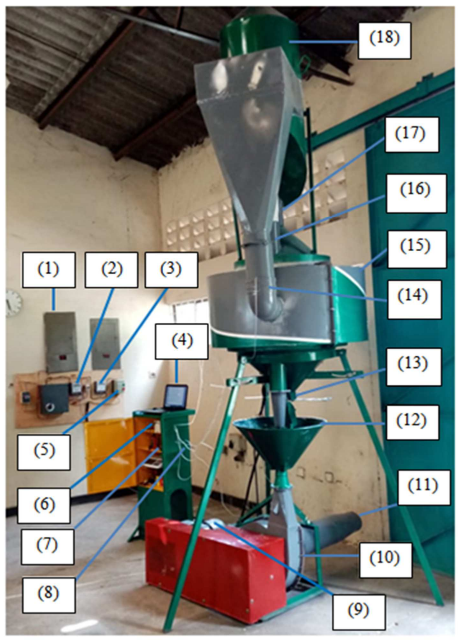

Figure 2. *Actual experimental vertical pneumatic maize grain dryer.*

Key: (1) is power supply, (2) is electric heater power meter, (3) is blower power meter, (4) is personal computer, (5) is blower power switch, (6) is data logger, (7) is proportional integral derivative (PID) temperature controller, (8) is platinum (PT)-100 temperature sensors, (9) is electric motor, (10) is blower, (11) is ambient air duct, (12) is feed hopper, (13) is slide valve, (14) is separated air duct, (15) is drying chamber, (16) is air-maize grain mixture duct, (17) is separated maize grain duct and (18) is cyclone separator.

2.2. Dryer Operation

The operation of the dryer involved starting the motor and switching on the electric heater. The desired air temperature for maize grain drying was set on the proportional integral derivative (PID) controller (Model 3300, Cal Controls, United Kingdom). The dryer was loaded with maize grain using the feed hopper. Due to venturi effect created at the intake by moving airstream, the grain was vacuum-picked and transported through a vertical duct to the cyclone. The separation of air-grain mixture occurred in the cyclone. The grain was conveyed to the drying chamber by gravity while the air to the plenum chamber, heated and used in drying. The grain was continuously re-circulated throughout the drying period. The dryer was a single air pass and hence exhaust air was released to the atmosphere without recirculating.

2.3. Determination of Effect of Initial Moisture Content of Maize Grain on Moisture Removal Rate and Energy Used in Drying

The effect of initial moisture content (MC) of maize grain on moisture removal rate (MRR) and energy used in drying was evaluated in levels of 20%, 25% and 30%, wet basis (wb). The levels were within the range of MC of maize grain at harvesting [18]. A laboratory experiment was conducted to determine initial MC of maize grain at the selected levels. The experiment involved sub-dividing 70.0 kg of dried maize grain into 9 equal portions and rewetted with equal amounts of tap water at a temperature of 18°C. The initial moisture content of the maize grain was 11.4%, wb.

The MC of the rewetted maize grain was monitored at an interval of 15 minutes for a period of 9 hours. This involved randomly collecting samples of the rewetted maize grain from each container. The samples were mixed together, whipped to remove surface moisture and divided into three portions each weighing 25.0 g. Each portion of the samples was placed in labeled and empty moisture cans of known weight. The moisture cans and wet samples were placed in a constant temperature oven set at a temperature of 105°C for 24 hours [38]. The samples were removed from the oven and allowed to cool. The weight of the samples was measured using Ohaus Scout Pro digital balance (Model: Scout Pro SPU6000, Ohaus Corporation, Pine Brook, NJ USA). The moisture content of the samples was evaluated based on equation 1 [39] where, MC is moisture content of the sample (%, wb), W_i is initial weight of the sample (g) and W_f is final weight of the sample (g).

$$MC = \left(\frac{W_i - W_f}{W_i}\right) \times 100 \quad (1)$$

The laboratory results indicated that the MC level of 20%, wb, was obtained by rewetting the maize grain for 0.75 hours, 1.75 hours for 25% and 5.75 hours for 30% as shown in Table 1.

Table 1. *Rewetting and resulting moisture content of maize grain.*

Rewetting time (hr)	Mean moisture content of maize grain (%, wb)
0.00	11.4
0.75	20.0
1.75	25.0
5.75	30.0

The evaluation of effect of initial MC of maize grain on MRR and energy used in drying involved several experiments. In the first experiment, 70.0 kg of maize grain with initial moisture content of 11.4% wb was rewetted in tap water at temperature of 18°C for 0.75 hours. This was to obtained moisture content level of 20% wb. The excess surface water was drained before the rewetted maize grain was loaded and dried for 2 hours in PGD. The drying process involved continuously re-circulation of the grain. The mass flow rate (MFR) of the grain was controlled at 771kg/kg.h using horizontal circular orifice with diameter of 0.042 m. Similarly, the MFR of the drying air was 547 kg/h. Further, the plenum chamber air temperature was also controlled at 70°C throughout the drying period. This was achieved by use of platinum (PT) 100 temperature sensors which continuously monitored the air temperature in the plenum chamber. The sensors translated the air temperature into feedback signal to proportional integral derivative (PID) controller (Model 3300, Cal Controls, United Kingdom). The PID controller responded accordingly by sending forward signal to the electric heater to actuate ON and OFF actions thereby ensuring that the plenum chamber air temperature was maintained at set point of 70°C throughout the drying period.

The MRR and energy used in drying were monitored at an interval of 15 minutes throughout the drying period. The MRR was determined based on equation 2 [40] where, W_2 is weight of dried maize grain (kg), W_1 is weight of undried maize grain (kg), M_1 is moisture content of undried maize grain (%) and M_2 is moisture content of dried maize grain (%).

$$W_2 = W_1 - \frac{W_1(M_1 - M_2)}{100 - M_2} \quad (2)$$

The energy used in drying was proportioned to energy for air heating (E_a) and that for maize grain transportation (E_g) and measured using two identical digital power meters (Model DDSS28II, Wenzhou linier electric co. Ltd, China). Three replications were performed and mean values of MRR, E_a and E_g determined.

Similar experiments were repeated but using maize grain with initial MC of 25% and 30%, wb. The initial MC of 25% was obtained by rewetting dried maize grain with initial moisture content of 11.4% (wb) in tap water at 18°C for 1.75 hours while that for 30% was 5.75 hours. The plenum chamber air temperature, air and maize grain MFR remained the same as in the first experiment.

3. Results and Discussions

The MRR ranged from 0.0914 kg/kg.h to 0.0357 kg/kg.h for maize grain with initial MC of 20%, 0.1043 kg/kg.h to 0.0556 kg/kg.h for 25% and 0.1185 kg/kg.h to 0.0705 kg/kg.h for 30%, wb. Figure 3 shows variation of MRR with drying time for the maize grain with initial MC of 20%, 25% and 30%. A decreasing trend in MRR plots with drying time was observed in all the MC levels. The MRR plots were non-linear and gradually decreased with increased in drying time. The MRR was higher at 0.25 hours and lower at the end of drying period in all the MC levels. The MRR for maize grain with initial MC of 30% was higher compared with that for 25% and 20%. This showed that the initial MC of the maize grain had considerable effect on MRR in drying.

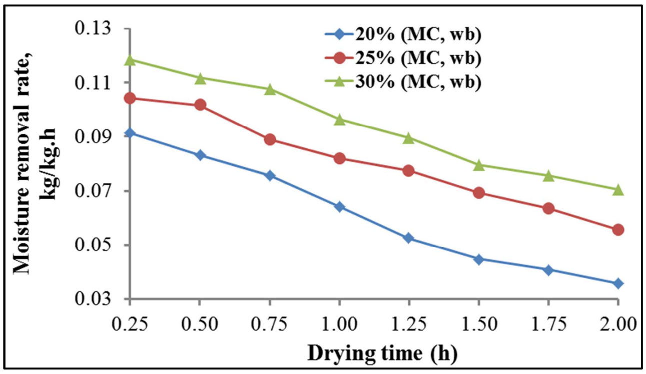

Figure 3. *Variation of moisture removal rate with time in maize grain drying with selected initial moisture contents.*

The analysis of variance (ANOVA) results indicated significant difference ($P < 0.05$) in MRR for all the initial MC levels. The Fisher's least significant difference ($LSD_{5\%}$) did not show any statistical difference in MRR between the maize grain with initial MC of 20% and 25%, and 25% and 30%. However, the MRR between maize grain with initial MC of 20% and 30% was significantly difference.

The energy used for air heating (E_a) in maize grain drying with initial MC of 20% and 25% was 10.5 kWh while that for 30% was 10.6 kWh. Figure 4 shows variation of E_a with time in maize grain drying with initial MC of 20%, 25% and 30%. An increasing trend in E_a plots with drying time was observed in all the MC levels. Further, the E_a plots for all the MC levels were indistinct and overlaid. This implied that the initial MC of maize grain did not have considerable influence on E_a in maize grain drying.

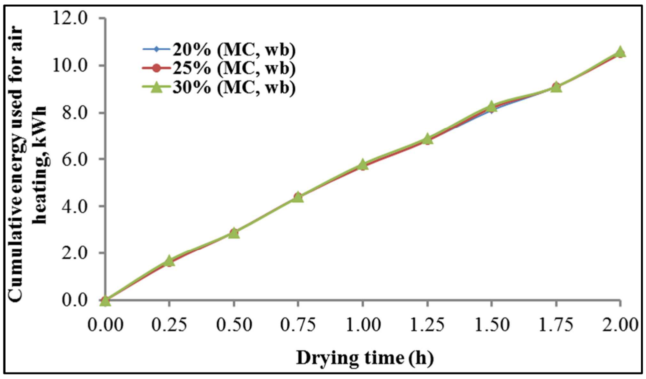

Figure 4. *Variation of energy used for air heating with time in maize grain drying with selected initial moisture contents.*

The ANOVA results did not reveal any significant effect ($P > 0.05$) of initial MC of maize grain on E_a in maize grain drying. The Fisher's $LSD_{5\%}$ results did not show existence of statistical difference in E_a between the MC of 20% and 25%, 20% and 30%, 25% and 30%.

The energy used for maize grain transportation (E_g) in maize grain drying with initial MC of 20% was 4.6 kWh, 4.8 kWh for 25% and 5.0 kWh for 30%, wb. Figure 5 presents variation of E_g with drying time for the maize grain with initial MC of 20%, 25% and 30%. The E_g plots had similar trends and increased with drying time in all the MC levels. The plots of were similar but distinct. The E_g for maize grain with initial MC of 30% was 0.4 kWh and 0.2 kWh higher than that for 20% and 25%, respectively. This implied that E_g increased with increased in the initial MC of maize grain.

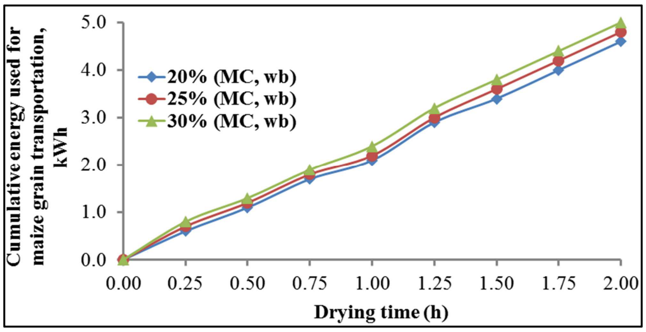

Figure 5. *Variation of energy used for maize grain transportation with time in maize grain drying with selected initial moisture contents.*

The ANOVA results did not show any significant difference ($P > 0.05$) in E_g for all the MC levels. The Fisher's $LSD_{5\%}$ results did not indicate statistical difference in E_g in maize grain drying between MC of 20% and 25%, 20% and 30%, 25% and 30%.

4. Conclusion

The initial moisture content of maize grain had significant effect ($P < 0.05$) on moisture removal rate. This implied that the higher the initial moisture content of maize grain the higher the moisture removal rate in drying. However, the initial moisture content of maize grain did not have any significant effect ($P > 0.05$) on the energy used for air heating and grain transportation. This indicated that the energy used for air heating and grain transportation in maize grain drying did not depend on the initial moisture content of the grain.

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