Solar Dryer Design for Reduced Levels of Aflatoxin Contamination in Forage Products; An Attempt to Mitigate the Consequences of Climate Change

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Abstract: ***In dairy production, feeds and feeding account for more than 70% of the production cost. In the tropics, forage harvesting and conservation coincide with the peaks of the rainy season. This implies that there limited chances of having timely forge drying leading to wastage and toxin contamination. In most parts of northern Uganda, the long dry seasons are characterized by forage feed shortages in quality and quantity. This study therefore aimed at developing a forage dryer design that could help dairy farmers curb the loss associated with pasture farming-based dairy production. To assess the two solar dryer prototypes including open drying as a control, similar forage quantities were loaded and moisture content determined at 2-hour intervals between 7: 00-19: 00. Using open drying, the drying rates decreased with the increasing density of Brachiaria forage loaded in the solar dryer. Generally, the rate of drying decreased at decreasing rates with a decrease in moisture content of the Brachiaria forages. As a consequence, using the second derivatives of the regression equations, minimum forage moisture contents of 30.1, 10.4, 10.4, and 5.8 were obtainable at 21.05, 17.17, 17.17, and 15.8 hours, respectively. Similarly, in non-ventilated solar dryers, the drying rates decreased with the increasing density of Brachiaria forage loaded in the solar dryer. Generally, the rate of drying decreased at decreasing rates with the decrease in moisture content of the Brachiaria forages. As a consequence, minimum forage moisture contents of 5.3, 7.5, 19.6, and 31.7 were obtainable at 15.5, 17.0, 17.1, and 19.4 hours, respectively. At the forage loading density of 2.5kg/m2, there was a significant difference ($p<0.05$) in both the drying rates and minimum obtainable moisture contents of the forages. However, when the forage loading density was increased to 5, 7.5, and 10.0 kg/m2, higher drying rates were obtained due to the ventilation of the solar dryer. As a consequence of the increase in drying rates with drying hours, minimum obtainable moisture contents of 27, 37, and 34 were observed at; 17, 16, and 23 hours after loading the none ventilated solar dryer. For the case of the ventilated solar dryer, however, minimum obtainable moisture contents of 6.3, 1.6, and 15 were observed at; 17, 20.6, and 23 hours after loading the ventilated solar dryer. Whereas solar drying increased the rates of drying, a well-ventilated solar dryer offers the optimum solar dryer design for best results.***

Keywords: Solar dryer, forage conservation, dairy production, Northern Uganda

1.Introduction

Africa accounts for 33% of the malnutrition-related deaths due to food insecurity, safety, and toxin-associated challenges due to improper forage feed drying and conservation (Wiseman, 2006). Since food safety is a key requirement in ensuring human health in all countries, there is a worldwide concern about toxin-based food and feed contaminants (Ok et al., 2009). However, according to Shepherd (2003), both food safety matters and toxin-related challenges strongly correlate with food insecurity. This implies that the associated malnutrition-related deaths to a greater extent are a consequence of food insecurity and toxicity (Shepherd, 2003). Like all developing countries, Uganda still faces challenges of food insecurity and poverty leading to the utilization of toxin-contaminated agricultural products (Schmidhuber & Tublello, 2007). Since the utilization of such products is associated with malnutrition and reduced livestock performance (Daniel et al., 2009), feed decontamination is a key requirement for improving nutrition, livelihood, and income security. This implies that attempts should be made to ensure proper forage drying to curb toxin-related contaminations that come with poor forage drying technologies.

In the tropics, forage harvesting and conservation coincide with the peaks of the rainy season. This implies that there limited chances of having timely forge drying leading to wastage. Yet, in most parts of northern Uganda, the long dry seasons are characterized by forage feed shortages in quality and quantity. This study therefore aimed at developing a forage dryer design that could help dairy farmers curb the loss associated with pasture farming-based dairy production.

In dairy production, feeds and feeding account for more than 70% of the production cost. However, feed forage materials are generally hygroscopic containing both bound and unbound water. During the drying process, the vapor pressure of the forage increases when heated at constant moisture content. So as the forage dries, moisture transfers from the product to the environment at lower vapor pressure. At the same time, water and heat are lost from the forage surfaces as latent heat of fission hence cooling the forage. At a steady-state, the rate of drying depends on both heat and vapor pressure gradient which both depend on the rate of airflow (Sodha et al., 1985). For the case of forages that involve deep layer drying, movement of moisture takes place at the bottom which is the drying zone that maintains moisture equilibrium between the forage mass and drying air. Therefore to accelerate the drying process, labor-saving solar dryer technologies need to be the top priority for sustainable dairy production. As a consequence, this study was designed to develop a solar dryer that could timely dehydrate the forages with limited loss in quality and quantity.

2.Materials and Methods

Structural designs of the dryer prototypes

The materials for making simple solar dryers were cheap and easily obtainable in the local market in Lira city. The transparent top cover is a clear polyvinyl chloride (PVC) plastic sheet with a total surface area of 1.22 m by 0.90 m. The dryer cabinet was made of 25 mm plywood. The front is higher than the rear giving the top cover inclination of 300 Vents were made at the low end of the front of the cabinet and at the upper end of the back of the cabinet to facilitate and control the convectional flow of air through the ventilated solar dryer while the non-ventilated had no holes. A drying tray was constructed with wire mesh, which fitted snugly and covered the entire floor of the dryer. Access doors in both dryers were also provided at the back of the cabinet to allow the loading of the drying tray with forages.

Forage drying efficiency evaluation

The evaluation was carried out between 07: 00 hrs. to 19: 00hrs. During the experimentation, three solar drying regimes were tested (open drying, non-ventilated solar drying, and ventilated solar drying). For each of the solar drying regimes, Brachiaria forages with identical moisture contents were loaded at 07: 00 at varying densities of 2.5, 5.0, 7.5, and 10kg/m3. At intervals of 2 hours, samples of 100g were taken to determine the moisture content using a laboratory drying oven.

3.Data Collection

During the testing period, the temperature profile of each drying regime was determined by measuring the hourly temperatures inside the drying cabinet and the ambient air between the hours of 08.00 and 18.00. The dryers were loaded with similar quantities of Brachiaria forages while varying the loading density each day and the forage weights were measured. The dryer performance was evaluated using the drying rate and the system drying efficiency as well as determining the gradient functions of each drying curve. The drying rate, which is the quantity of moisture removed from the food item in a given time, was computed from the equation,

$dy = (mi - mf) \times 100\%$

according to (Itodo et al., 2002). The drying efficiency was computed from the equation, $\omega d = (MwLw) \times 100\%$

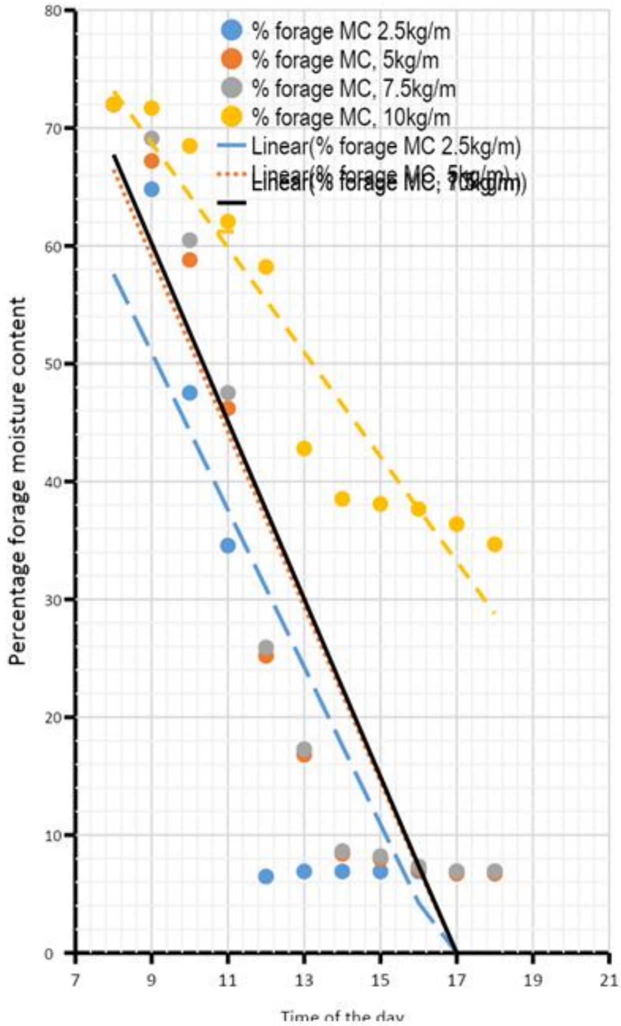
Data analysis

Polynomial contrasts were used to test for linear and quadratic effects of the inclusion of drying duration of each drying type (open drying, non-ventilated solar drying and ventilated solar dryer for each drying density (kg/unit area). Study parameters were considered significantly different at P<0.05. Second-order polynomial regressions were also fitted to each drying treatment. Furthermore, regressions equations were differentiated to determine the point of inflection on each response curve hence determining the equilibrium moisture content at maximum drying.

4.Results

Effect of solar drying on the drying rates of Brachiaria forages

The effect of forage quantity loaded in the solar dryer on rates of drying is displayed in Fig.1. Using open drying, the drying rates decrease with the increasing density of Brachiaria forage loaded in the solar dryer. Generally, the rate of drying decreased at decreasing rates with a decrease in moisture content of the Brachiaria forages. As a consequence, using the second derivatives of the regression equations in (Fig.1a) minimum forage moisture contents of 30.1, 10.4, 10.4, and 5.8 were obtainable at 21.05, 17.17, 17.17, and 15.8 hours, respectively. Similarly, in non-ventilated solar drying, the drying rates decreased with the increasing density of Brachiaria forage loaded in the solar dryer. Generally, the rate of drying decreased at decreasing rates with a decrease in moisture content of the Brachiaria forages. As a consequence, using the second derivatives of the regression equations in (Fig.1a) minimum forage moisture contents of 5.3, 7.5, 19.6, and 31.7 were obtainable at 15.5, 17.0, 17.1 and 19.4 hours, respectively.



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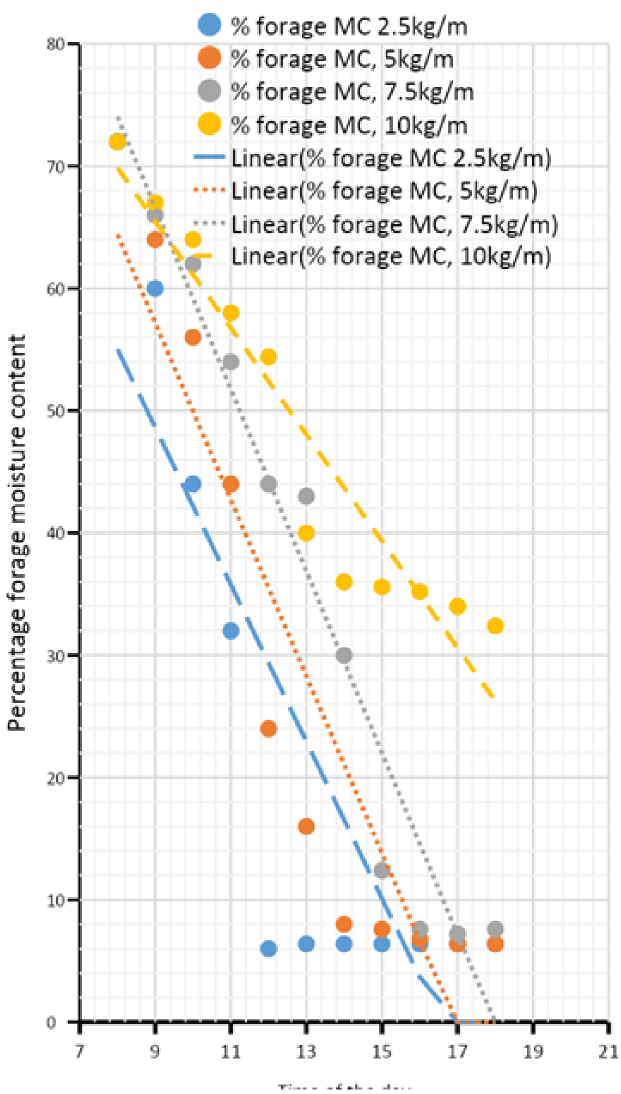
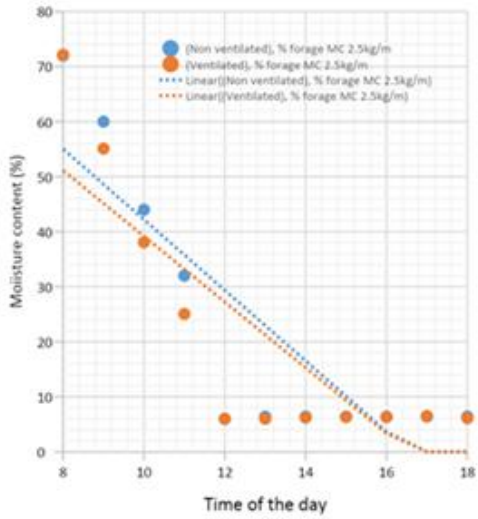


B

Figure.1. Forage drying rate curves of (a) open drying, and (b) Solar dryer-based drying.



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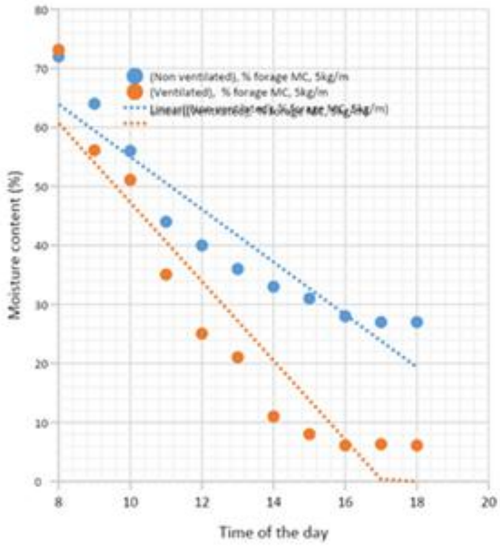

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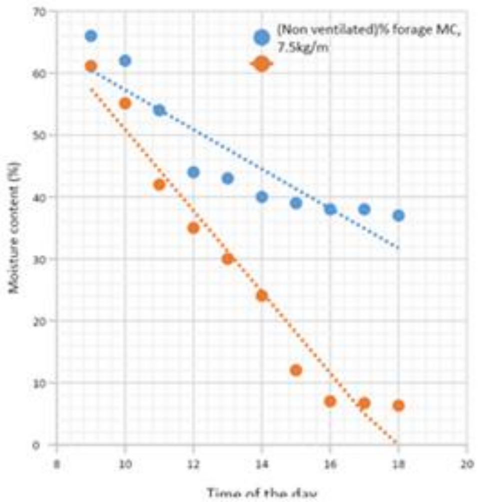
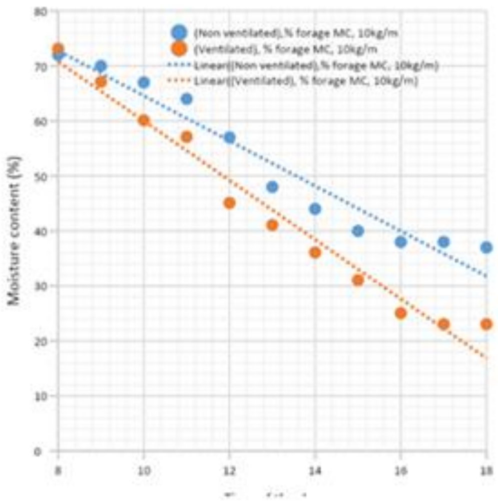


C

The Effect of ventilation on the drying characteristics of Brachiaria forage is displayed in Fig.2. At the forage loading density of 2.5kg/m2, there was a significant difference ($p<0.05$) in both the drying rates and minimum obtainable moisture contents of the forages. However, when the forage loading density was increased to 5, 7.5, and 10.0 kg/m2, higher drying rates were obtained due to the ventilation of the solar dryer. As a consequence of the increase in drying rates with drying hours, minimum obtainable moisture contents of 27, 37, and 34 were observed at; 17, 16, and 23 hours after loading the none ventilated solar dryer. For the case of the ventilated solar dryer, however, minimum obtainable moisture contents of 6.3, 1.6, and 15 were observed at; 17, 20.6, and 23 hours after loading the ventilated solar dryer.



D

Figure.3 Forage drying rate curves of (a) 25kg/m^2, (b) 5.0 kg/m^2, (c) 7.5 kg/m^2 and (d) 10kg/m^2

5.Discussion

In northern Uganda, Over 75% of the variable input in dairy production is accounted for by availing forages to the lactating cows (Nviiri et al., 2016). Whereas the forages are readily available in the tropical agro-ecologies like in Uganda, great seasonal variations have rendered it impossible to provide forage to dairy cattle throughout the year without conservation. In developing communities, especially in northern Uganda, a great capacity gap exists making it challenging to preserve fresh forages as silage leaving haymaking the most suitable forage conservation alternative (Nviiri et al., 2021). However, the peak forage production coincides with peak rains, and hence moisture content as well as limited sunshine for hay forage drying leads to mold growth and rotting. This implies that technologies that facilitate fast drying during forage growing and harvesting seasons cannot be left behind. This study therefore aimed at identifying the most suitable forage dehydrating solar design.

From this study, using open-air drying generally, the rate of drying decreases at a decreasing rate with a decrease in moisture content of the Brachiaria forages (Fig.1). This is attributed to the fact that open sun drying simply exposes the forages to solar radiation. Such exposure implies that a fraction of the solar radiation increases the forging temperature resulting in the emission of long-wavelength thermal radiation, convective heat loss, and mass transfer of moisture from the forage surface to the ambient air (). As a consequence drying solely depends on the resultant diffusion process (Sodha et al., 1985, 1987). Besides, a great amount of heat is reflected in the atmosphere as reported by (Tomar, V et al., 2017). Therefore due to uneven heat distribution, variation in relative humidity gradient, and convectional airflow, forage drying takes place on the surface of the forage bales.

Similarly, in non-ventilated solar drying, the drying rates decrease with the increasing density of Brachiaria forage loaded in the solar dryer. This could be attributed to the fact that in such a passive direct solar dryer, the solar radiation directly incident the green forage material while the reflected longer wavelengths cannot pass through the transparent material resulting in a greenhouse effect. Consequently, the resultant temperature increase increases the kinetic energy of the water molecules in the forge. However, the rate of drying in a non-ventilated dryer type doesn't differ greatly from that of open-air drying. This could be attributed to the fact that besides increasing the temperature, the relative humidity of the ambient air increases hence lowering the humidity gradient between the forges and surroundings (Ekechukwu and Norton, 1999a; Onyegebu et al., 1994). As a result, the increase in temperature by the non-ventilated solar dryer is outweighed by the decrease in the relative humidity gradient. The observations from this study are in agreement with findings by several Authors (Esper & Muhbauer, 1998; Sodha et al., 1985; Jayaraman et al., 2000) who reported a higher drying process in a cabinet type dryers than in open drying due to higher ventilation of the cabinet dryer. However, in such dryers, discoloration of the green forage materials due to solar energy exposure was observed. This implies that the precursor of vitamin A and anti-oxidant content of the resultant hay materials shall be greatly lowered. So, photoselective materials which have been indicated to reduce both color and anti-oxidant losses need to be included to improve the quality of the hay produced by the dryers (Milczarek et al., 2016). In addition, the challenges of discoloration could be overcome by reducing insolation transmission through indirect heat extraction from the solar radiations (Goel et al., 1987; Jain, 2007).

6.Conclusion

By controlling the airflow rate, ventilated solar dryers produce the best results. In small ventilated and non-ventilated solar dryers the effect of airflow rate on the maximum evaporation rates depends on the ratio of total drying area to the cross-sectional area of the drying compartment. Solar forage drying brings together the complexities of internal forage structures and ruminant nutrition.

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