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CASE STUDY

Comparative assessment of three low-capacity drying systems using the analytical hierarchy process

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Abstract
The study assessed the technical performance of three alternative drying systems for drying maize by smallholder maize farmers in Ghana. The three dryers considered were the AflaStop (EasyDry M500) dryer, STR Column dryer, and the Solar Bubble dryer. The Analytical Hierarchy Process (AHP) was used for the comparative analysis and selection of the best alternative drying system based on its technical performance, durability, ease of use, cost of manufacture and operational cost. The drying rate and drying efficiency determined for the AflaStop, STR Column, and the Solar Bubble dryer were 2.20 %/h, 1.90 %/h, 0.98 %/h and 81.07 %, 64.65 %, 36.17 %, respectively. Considering a global priority value of 41 %, the STR Column drying system was selected over the AflaStop and the Solar Bubble dryers which had priority values of 34 % and 25 % respectively. The use of the AHP model was successful in selecting among three locally available low-capacity dryers, most suitable for maize drying by smallholder maize farmers, in Ghana.

Keywords: Low-capacity Dryers, Drying Rate, Drying Efficiency, Analytical Hierarchy Process, Global Priority Value

Introduction

Maize production in Ghana accounts for more than half of the total amount of grains produced (Ragasa *et al*., 2014) and is mainly done under rain-fed conditions by smallholder farmers who are poorly resourced (Darfour and Rosentrater, 2016) and are characterized by limited land availability, limited financing and inputs, high levels of risk and low market participation (Chamberlin, 2007). Preeminent post-harvest losses (PHL) of food crops within the supply chain in developing countries happens during the storage phase, however, the use of dryers to dry grains properly before storage can reduce PHL and have a significant impact on food availability (Kumar and Kalita, 2017).

In Ghana, most smallholder grain farmers usually leave their matured grains in the field (delayed harvesting) to dry or dry their grains on the bare floor along the shoulder of roads or on tarpaulins in the open-sun near their home (Akowuah *et al*., 2018). Although these methods of drying is considered the most cheapest due to the free energy source (sun) for drying, the process is associated with many disadvantages including contamination by animals, rain and dust, intensive labour activities and long drying periods which promote the growth of moulds and mycotoxins (Kaaya and Kyamuhangi, 2010). Existing commercial gas- or diesel-powered mechanical dryers are fast and provide a high-quality product, however, such dryer are rarely patronized by smallholder farmers (Akowuah *et al*., 2015) mainly due to their high installation and operating costs. This therefore has created a priority of most smallholder farmers in sub-Saharan Africa to own and operate their own low-cost batch drying system that meet their production capacity which is typically less than 3 tons per hectare (Cairns *et al*., 2013; Pauw, 2022).

In recent years, prototypes of such low-cost batch drying systems such as the Solar Bubble Dryer developed by GrainPro Inc., the AflaSTOP dryer developed with support from the Gates Foundation and the STR dryer developed under the USAID Post Harvest Loss Reduction Innovation Lab (PHLIL) among others have been introduced in Ghana and other places in sub-Saharan Africa. According to Chua and Chou (2013), low-capacity drying systems are more suitable for smallholder farmers in developing countries. The authors emphasized that such drying systems should have low initial capital cost, easy to operate with no complex operational protocol, and effective for producing quality grains.

The successful assessment of such low-capacity drying technologies is critical to drive scale-up from prototype to commercialization and adoption by smallholder farmers. However, the selection of a suitable drying system by a smallholder farmer from among other appropriate low-capacity batch drying systems can pose an arduous decision-making challenge due to various factors including geographic location, dryer performance, capacity, cost, and dryer configuration or setup.

In comparing alternative solutions, the Analytic Hierarchy Process (AHP) developed by T.L. Saaty is the oldest and one of the most useful methods that helps in ranking problems and occasionally used for selecting the best among several alternatives (Vaidya and Kumar, 2006). The AHP compared to other decision tools has distinguish features which helps to transform evaluations into numerical values for ease of analysis and comparison throughout the entire problem space. Each element of the hierarchy is given a numerical weight or priority, which enables varied and frequently incommensurable items to be compared to one another in a logical and consistent manner (Saaty, 2008). Jorge *et al*. (2015) used the AHP to select a long -life tomato drying system, while Armah *et al*. (2021) used it in selecting the appropriate maize drying platform for a solar bubble dryer. In this study, the AHP model was applied to evaluate and select the best alternative among three low-capacity drying systems for maize drying by smallholder maize farmers in Ghana.

Materials and Methods

Experimental study

The performance assessment of the dryers was performed at Kwame Nkrumah University of Science and Technology (KNUST), in the Department of Agricultural and Biosystems

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Engineering. It is located at Ashanti Region of Ghana with latitude 06˚41'5.67" N and longitude 01˚34'13.87" W.

Description of drying systems and experimental procedure

The representation of the AflaStop (EasyDry M500) Dryer, STR Column Dryer, and the Solar Bubble Dryer is showed in Figure 1, 2 and 3, respectively, with operational capacities of 0.5 tonnes for the AflaStop and STR Column Dryer and 1 tonne for the Solar Bubble Dryer.

Experimental procedure for dryers

About 250 kg of a local white maize variety known as *Omankwa* was harvested from a local farm and used for the performance evaluation of each dryer. Tests conducted were used in determining drying rate of grains and the drying efficiency of the drying systems. The three dryers were assembled as shown in Figures 1, 2 and 3 for the experiments. A pre-calibrated moisture meter (Dicky-John miniGAC plus moisture analyser with accuracy of ±0.1 %, USA) was used to determine the maize samples' initial moisture content (MC). Temperature distribution in the drying chamber was observed with temperature sensors, TinyTag data logger (model TGP-4017; Gemini Data Loggers, Chichester, UK.) which were positioned in the dryers as shown in Figures 4, 5 and 6. All the data loggers were set evenly to log temperature and humidity readings at 10 min time interval. In monitoring the moisture loss in grains dried in

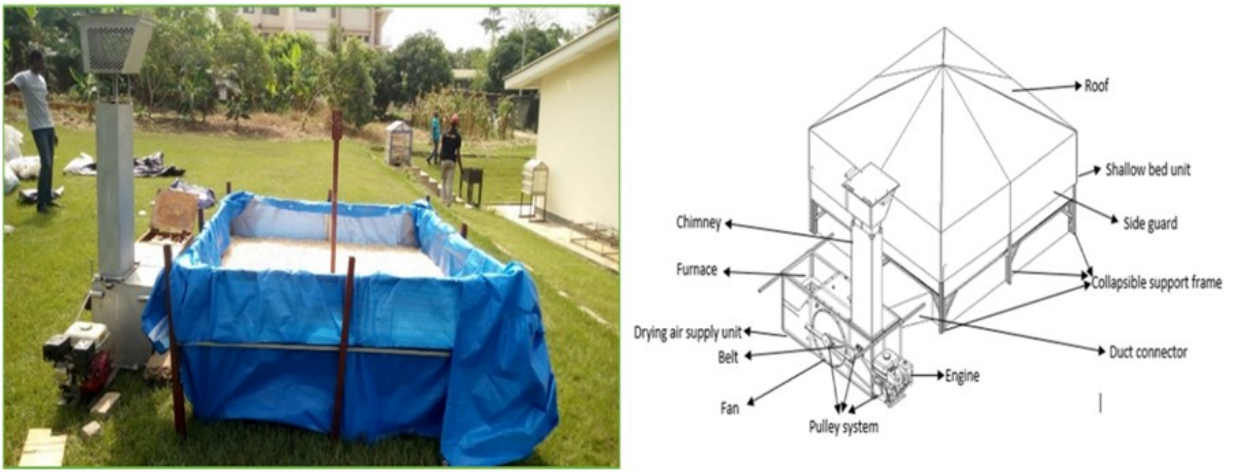

Figure 1 Installed AflaStop dryer at KNUST and an insert of its schematic view from Rossouw (2016)

Figure 2 KNUST STR column dryer with the CAD model

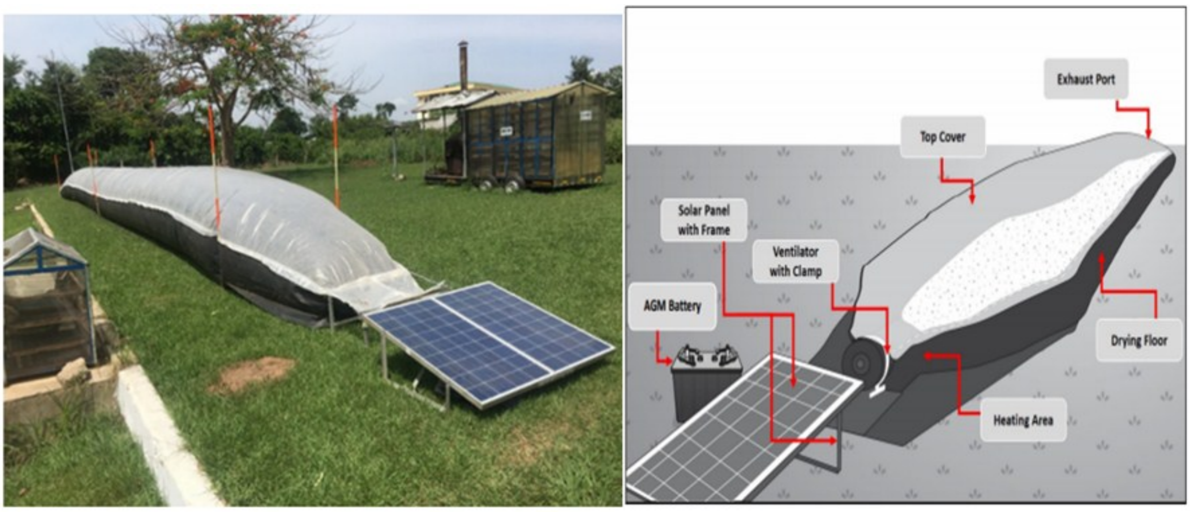

Figure 3 Solar bubble dryer setup at KNUST with an insert of its labelled components

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the dryers, three samples of maize grains were collected from three different points at each section of the AflaStop dryer (see Figure 4), at the inner and outer sections at three different points P1, P2 and P3 in the STR Column dryer (see Figure 5) and three samples from each section in the Solar Bubble Dryer (see Figure 6) for analysis.

The MC during the experimental drying of maize grains were monitored hourly and grains were sampled at the different positions and thoroughly mixed before readings were recorded. At each period the average of measurements were calculated for analysis using the moisture analyzer. The process was then repeated until attaining the recommended final MC (14 % to 12 % wet basis) for the grains (Hodges and Stathers, 2012; Costa, 2014).

Dryer performance

Drying rate (DR)

The drying rate of maize samples varied with temperature of the drying air and the initial MC. Drying rate was determined using Equation 1, where *DR* = drying rate (%/h), m_i = initial MC on wet basis (%), m_f = final MC on wet basis (%) and t = drying time (h).

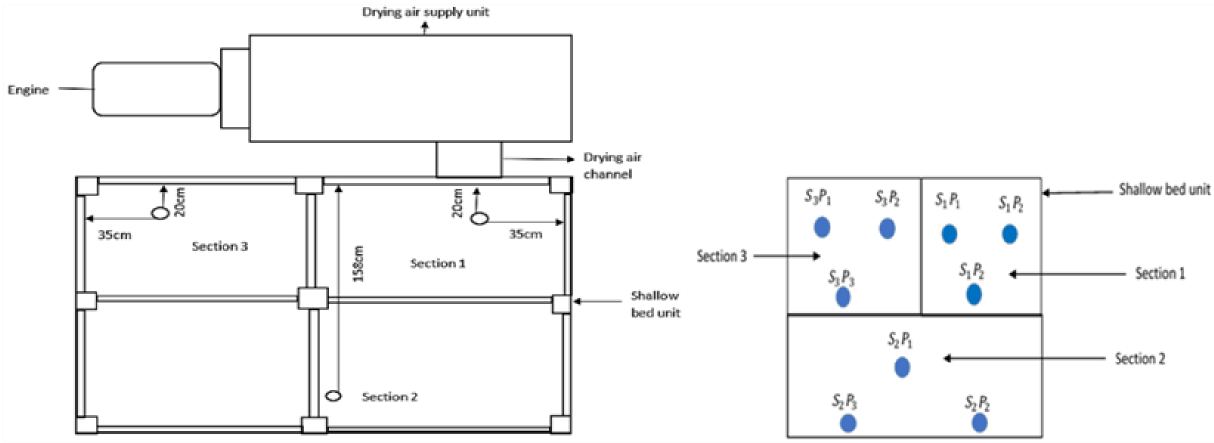

Figure 4 Plan view of the experimental setup showing points of data collec-

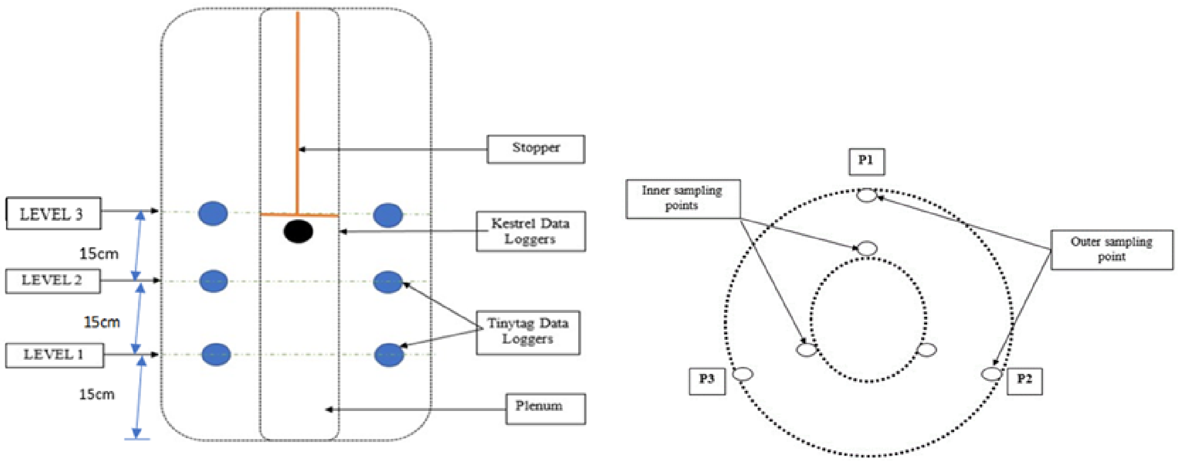

Figure 5 Longitudinal cross-section showing points of data collection and sampling

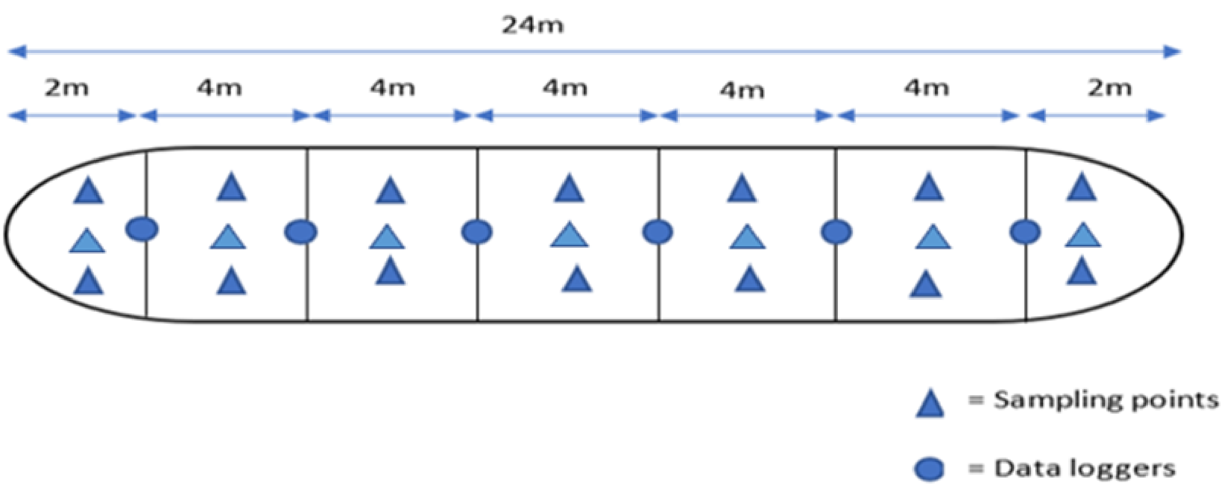

Figure 6 Layout of sampling points and data logging positions in the SBD

$$DR = \frac{m_i - m_f}{t} \quad (1)$$

Drying efficiency (η)

The efficiency of the drying process was considered as the ratio of the energy utilized to evaporate moisture from the maize grains to the energy within the drying air as expressed in Equation (2). Dhanushkodi *et al.* (2014) describes this as the overall effectiveness of a drying system. In the case of Solar Bubble drying systems, the overall effectiveness of the dryer is largely attributed to the solar collector's thermal efficiency (Vijayan *et al.*, 2016), which is expressed in Equation (3).

$$\eta = \frac{M_w L_v}{M_{air} C_{pair} \Delta T} \quad (2)$$

Where, η is drying efficiency (%), M_w is rate of moisture evaporation (kg/hr), L_v is latent heat of vaporisation of water (kJ/kg) (L_v in Aflastop drying = 2378.78 KJ/Kg, L_v in STR column drying = 2383.59 KJ/Kg), M_{air} is the mass flow rate of air (kg/h) (M_{air} in Aflastop drying = 2.83 Kg/h, M_{air} in STR column drying = 1.27 Kg/h) , ΔT is change in temperature between the ambient and drying air (˚C) and C_{pair} is specific heat capacity of air (1.005 KJ/kg ^{0}C).

$$\eta_c = \frac{m c_p \Delta T}{A_c I} \times 100 \quad (3)$$

Where m is mass flowrate (kg/s), C_p = specific thermal capacity (kJ/kg°C), A_c = the solar collector area (48 m^2) and I is solar radiation in the collector plane (362.7 W/m^2).

Selection of drying system

The AHP was used to assess the performance of the three low-capacity drying systems from data obtained from literature, manufacturing, operation, and the drying experiments performed on the dryers.

The AHP model application

In selecting the most suited drying system for smallholder farmers, consideration on design, economic and technical performance of the dryers were considered key input parameters for the evaluation process. Table 1 gives a description of all the criteria considered.

1. The procedure used for the AHP was in accordance with studies by Atanasova-pacemska *et al.* (2014) and Wolnowska and Konicki (2019), and summarized as follows:

   Modelling problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives as shown in Figure 7. The number of alternative drying systems out of which the selection was made were identified and written in the alternatives matrix **A = [A$_i$].** Where i = the number of alternatives (1, 2,

Table 1 Criteria for selection of best alternative drying system for maize drying

Symbol	Name of criterion	Description
C1	Drying rate	This defines the rate at which the product's internal moisture is evaporated and the degree to which the saturated air is removed from the product environment.
C2	Drying efficiency	This is a technical performance indicator of the system that considers the effectiveness of the drying system to the consumptive use of energy by the system.
C3	Durability	The selected drying system should last long enough amidst handling on farms and operation in remote areas.
C4	Ease of use	This considers the ease in setting up and operating the drying systems.
C5	Versatility	This focuses on the ability of the drying system to dry other food products to the recommended MC.
C6	Cost of purchase	This defines the initial cost of purchasing a drying system.
C7	Operational cost	This includes costs involved in operating the drying system such as maintenance cost, cost of fuel (if applicable), cost of technical staff or labour cost (if applicable).

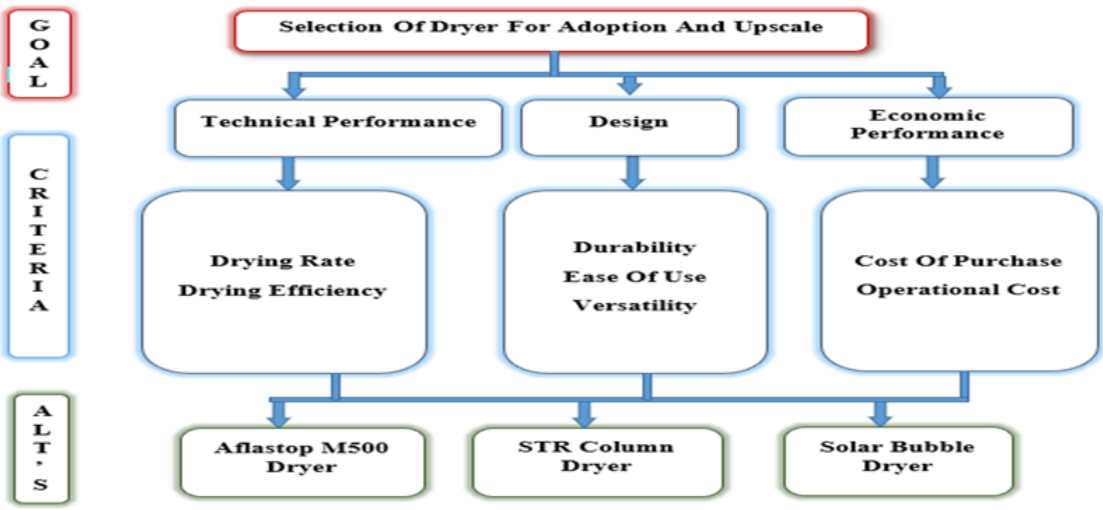

Figure 7 Structure of the Analytical Hierarchy Process for alternative dryers

3) and the criteria were written in a decision criteria matrix $C = [C_j]$. where j = number of criteria (1, 2, 3, 4, 5, 6, and 7).

2. Establishing priorities among the elements of the hierarchy by making judgements based on pairwise comparisons of the elements in the sub-criteria using Saaty's fundamental scale. With respect to the goal of the study, the relative importance of the criteria ($c = [c_{ij}]$) was determined based on extensive review of literature, technical consultancy and experiments on the impact each attribute has on the selection of the best drying system within the alternative drying systems. This was filled in a matrix, A of the size m. Where m = number of decisional criteria.

3. Development of vector weights. In the pairwise comparison matrix A, a vector $\boldsymbol{W} = [W_1, W_2 \ldots W_m]$ was used to indicate the weight given to each criterion. The steps used in determining the weight are as follows;
   a. In each A column, all entries in i of A are divided by the total input in column i. This generates a new matrix, Anorm. However, the total for each column in the Anorm matrix should be 1.
   b. The Wi was estimated as the average of the entries in row i of Anorm.
4. Determination of the consistency factor of the decision criteria matrix. This was done in order to prevent any bias from the decision maker since weights of the pairwise comparison matrix was based on the decision maker's choice. The steps below were used to check the consistency factor:

Determination of the maximum Eigen values of the pairwise matrix using the equation below

$$\lambda_{max} = \frac{1}{m} \sum_{i=1}^{n} \frac{i^{th} entry\ in\ AW^T}{i^{th} entry\ in\ W^T} \quad (4)$$

Where λ_{max} is maximum Eigen value, m is number of attributes, A is pairwise comparison matrix and W is the decision-maker's estimate weight

b. Determination of the consistency index, CI.

$$CI = \frac{\lambda_{max} - m}{m - 1} \quad (5)$$

c. Determination of the consistency factor by comparing CI to the random index, RI to obtain an appropriate value m for making the decision. The ratio of CI/RI is acceptable when the value is 0.1 or less. Values greater than 0.1 indicate serious inconsistencies in the pairwise comparison which creates the need to repeat the comparison for a more consistent result.

5. Determination of the relative weights for alternatives according to the conditions based on criteria. Steps 2 and 3 were applied to develop square matrices of size i (equal to the number of alternatives). The generated matrix number is the same as the number of criteria used.

6. Completing the performance matrix, in which the performance of alternatives was determined in each criterion, and details were recorded in the performance matrix P = [Pij].

Lastly, the sum weight of each priority is calculated by finding the product of each alternative weight associated with each criterion and the weight of each criterion to find its total; that is, $P \times WT$.

Results and Discussion

Reduction of moisture content during drying

Moisture loss in maize grains were compared in the AflaStop Dryer, STR Column Dryer and Solar Bubble Dryer as shown in Figure 8. The variations in MC of samples from the three alternative drying systems during the drying process was unique for each dryer. It was observed that MC decreased with an increase in drying time and drying process occurred within the falling rate period for all the three dryers.

Maize grains (250 kg) used for each drying experiment had an initial MC of 18.2 % (w.b). Grains from all three alternative drying systems were dried to an average final MC of 12% to 14% (w.b). MC of maize grains at 12 % to 14 % reduces the potential for deterioration and microbial growth during storage. After 2 hours of drying, grains sampled from the AflaStop dryer reached a desirable average MC of 13.8 %. This was followed by the STR column dryer with a final average MC of 12.5 % after 3 hours of drying while grains sampled from the Solar Bubble dryer reached an average MC of 13.3 % after 5 hours of drying. It was observed that the Solar Bubble dryer recorded the longest drying time while the AflaStop dryer recorded the shortest drying time among the three low-capacity drying alternatives considered to attain the minimum recommended MC of 14 % (see Figure 8).

Where the factors affecting drying rate such as initial MC, composition of material to be dried, size and shape, etc., are constant in this study, the major factors to consider are drying temperature and air velocity. This is proven by studies done by Amer and Gottschalk (2006) and Chinenye (2009), where both studies concluded air velocity as having the least impact on the

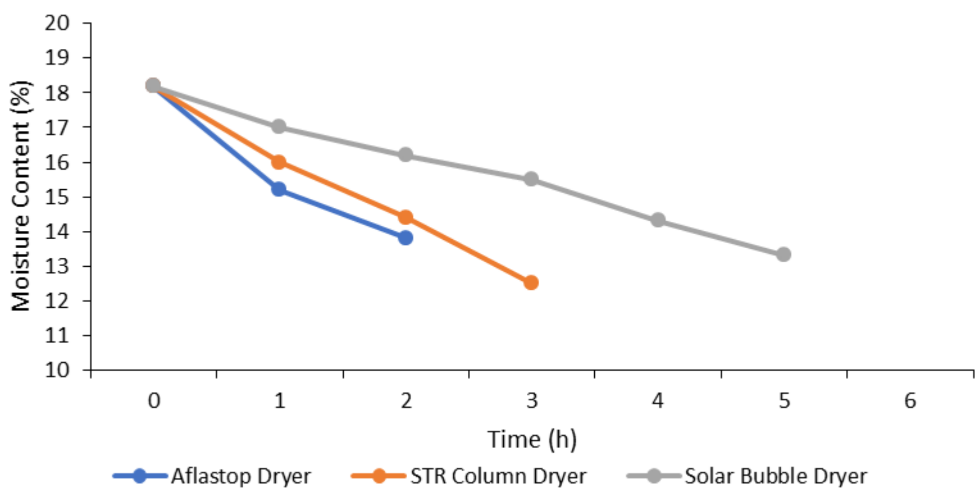

Figure 8 Moisture content variation with time in the three alternative dryers.

drying rate performance compared to temperature. Hence variations in the drying time of the alternative drying systems can mainly be attributed to the varying drying temperature experienced in each dryer as shown in Figure 9. Highest drying air temperature was in AflaStop Dryer, followed by STR Column Dryer and Solar Bubble Dryer.

Experimental test results and overview

The length of time used per each dryer in the drying process varies inversely to the drying rate of the system. This is clear in the drying rate performance for all the three alternative dryers in attaining the minimum recommended MC of 14% (see Table 2) used for the comparative analysis on the drying rates. The drying rates for the AflaStop dryer, STR Column dryer, and Solar Bubble dryer were determined as 2.20 %/h, 1.90 %/h, and 0.98 %/h for drying times of 1.97 hours, 2.65 hours and 4.75 hours respectively.

Application of AHP in selecting the best alternative dryer

The length of pairwise matrix is the same as the criteria number being used, thus the matrix in Table 3 is a 7 x 7 matrix. In obtaining the values of the pairwise comparison, the importance of column criteria in relation to the row criteria was evaluated using the scale of relative importance developed by T. L. Saaty. For instance, in the selection of the best alternative drying system for smallholder farmers, the drying rate was of strong importance compared to ease of use when selecting the best alternative drying system.

This was represented by 5.00 in C1/C4 when filling the matrix. The inverse of this comparison is also located in C4/C1 which was equal to 1/5 or 0.2. Also, when comparing the importance of a criterion with itself or another criterion of the same importance the judgmental value is always 1. This can be observed in comparing the importance of drying rate to cost of purchase in the selection dryer for adoption and upscale and explains why the value 1 is on the matrix' diagonal (Atanasova -Pacemska *et al.*, 2014).

The criteria for selection of best alternative drying system for maize drying in the case of a smallholder farmer in terms of cost of purchase, operational cost, drying rate, drying efficiency, durability, ease of use, and versatility at each weight is shown in Figure 10. The direct costs which were incurred during cost of purchase and operation had the highest weight of 0.266 each in the assigned criteria weights. Review from literature by Kaaya and Kyamuhangi (2010) and Akowuah *et al.* (2018) reveals the contribution of cost in the use of appropriate

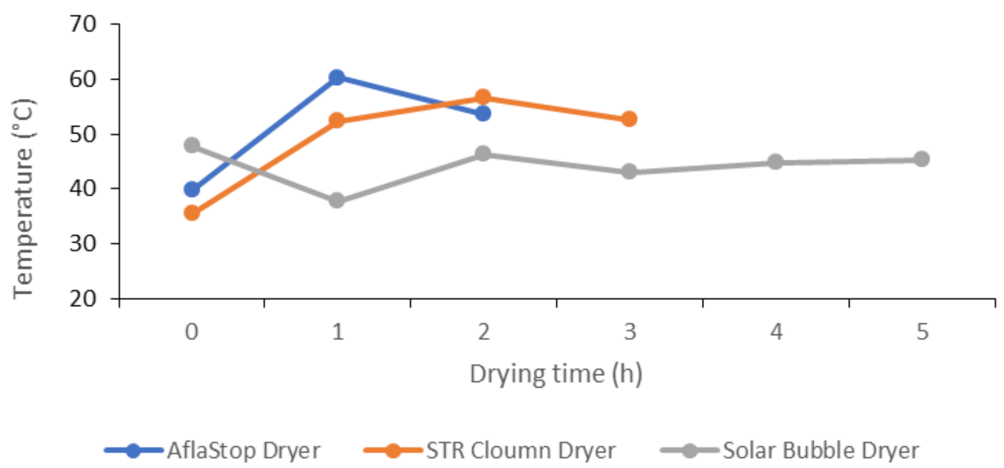

Figure 9 Temperature variations with time during the drying experimental in each dryer

Table 2 Summary of data on technical performance of the low-capacity dryers

Dryer	Drying Rate (%/h)	Drying Efficiency (%)	Drying Time (h)	Initial MC (%)	Final MC (%)	Maize mass (kg)
AflaStop Dryer	2.20	81.07	1.97	18.2	14	250
STR Column Dryer	1.90	64.65	2.65	18.2	14	250
Solar Bubble Dryer	0.98	36.17	4.75	18.2	14	250

Table 3 Decision criteria matrix from pairwise comparison between criteria

Criteria	C1	C2	C3	C4	C5	C6	C7
C1	1.00	2.00	3.00	5.00	7.00	1.00	1.00
C2	0.50	1.00	3.00	5.00	5.00	0.33	0.33
C3	0.33	0.33	1.00	3.00	3.00	0.20	0.20
C4	0.20	0.20	0.33	1.00	1.00	0.14	0.14
C5	0.14	0.20	0.33	1.00	1.00	0.11	0.11
C6	1.00	3.00	5.00	7.00	9.00	1.00	1.00
C7	1.00	3.00	5.00	7.00	9.00	1.00	1.00

C1: Drying rate, C2: Drying efficiency, C3: Durability, C4: Ease of use, C5: Versatility, C6: Cost of purchase, C7: Operational cost

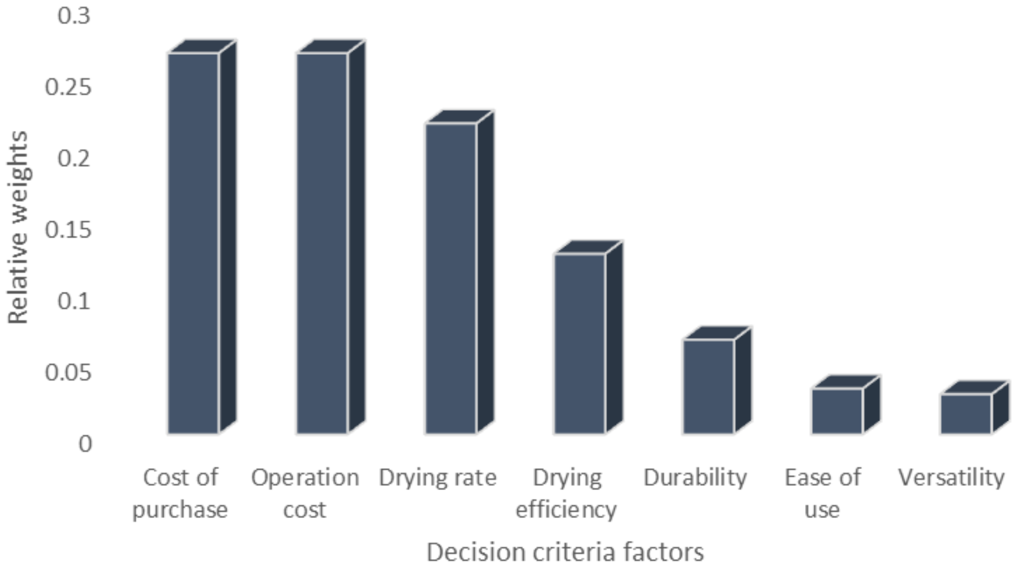

Figure 10 Relative weights of decision criteria factors

drying system by smallholder farmers who are characterized as being poorly resourced. This means that the availability of affordable drying systems has a lot of influence in the adoption of drying systems in Ghana and Sub-Saharan Africa to curb post-harvest losses due to improper drying systems.

Another important factor considered during the selection of the appropriate drying system is the drying rate. This rate at which the product's internal moisture is evaporated and the degree to which the saturated air is removed from the product environment is very crucial to the achievement of equilibrium MC or the desired MC for storage of grains. According to Jorge *et al.* (2015) the energy consumption accounts for 54 % of the sum of the cost in running a drying system. This means the efficiency of a dryer is directly linked to the cost of operation of the drying system which is a very critical consideration by smallholder farmers.

Furthermore, durability and ease of use are other important criteria which have to be considered when selecting an appropriate alternative drying system for adoption by smallholder farmers in Ghana. The need for a tough, robust and resilient to wear and damage from one drying season to the other is very important in the selection of appropriate drying system. Again, the high level of technicalities involved in the operations of some dryers discourages smallholder farmers from purchasing those drying systems. As such, there is the need for the system under consideration to be easy to use requiring fewer number of people to set up and operate and low technicalities in its application.

To assess the consistency of the decision criteria matrix developed, a consistency factor was calculated. Using a matrix size of 7 in the study, the RI value was 1.32. The ratio of the weighted sum value to the criteria weights for each row was determined and the average of 7.14 was obtained as the maximum Eigen-value (λmax) for the decision criteria matrix using Equation 4. Substituting the results into Equation 5, yielded a CI value of 0.024 which was used to finally calculate for the CR of 0.018 for the decision criteria matrix. The CR value obtained is less than 0.10, which is the tolerable amount for a 7x7 matrix. This indicates a high degree of consistency in the study were allocated weights for various criteria are clearly defined. These findings are consistent to research by other authors who applied AHP in achieving various specific goals (Jorge *et al.*, 2015; Wolnowska and Konicki, 2019).

Table 4 presents the alternative weights given for the performance of each alternative drying system with respect to the criteria used in the study. The selection of the most suitable dryer system from the alternative systems under consideration is difficult to assess due to the differences in the performance of each alternative system under each criterion. For example, when considering the drying rate, the AflaStop dryer (AD), which had a weight of 0.643 performs better than the STR column dryer (STRD) and the Solar Bubble dryer (SBD) whose weights were 0.286 and 0.074, respectively. However, when considering the operational cost, the SBD which had a weight of 0.633 was the best performing alternative followed by STRD with a weight of 0.261 with AD being the least performing alternative with a weight of 0.106. Nevertheless, as shown earlier in this study, the uneven contribution of each criteria weight influences the selection of the most suitable drying system. Therefore, the total of multiplications between the weight of each alternative (in Table 4) and the weight of each criterion (in Figure 10) will yield a vector which gives the priority value for the selecting the best alternative drying system.

From the priority values as highlighted in Figure 11, it can be deduced that the STR column dryer had the highest percentage priority value of 41 % compared to the Aflastop dryer (34 %) and the Solar Bubble Dryer (25 %). Thus, the STR column dryer is selected over the other alternative drying systems and considered as the most preferred alternative drying system for possible adoption by smallholder maize farmers in Ghana.

Conclusions

The application of the AHP innovative decision tool was successful for the comparison and selection of a suitable low-capacity maize dryer for adoption by smallholder grain farmers. Among three low-capacity drying systems for maize drying in Ghana at the smallholder level, the STR Column dryer was considered suitable based on its global priority value compared to the AflaStop dryer and the Solar Bubble dryer using the drying rate, drying efficiency, durability, ease of use, versatility, cost of purchase and operational cost of each drying system for the evaluation process. Smallholder farmers are therefore encouraged to access and utilize these dryers to reduce post-harvest losses in maize production.

Table 4 Performance matrix of alternative drying systems with respect to decision criteria

Criteria	AD	STRD	SBD
Drying rate	0.643	0.283	0.074
Drying efficiency	0.697	0.232	0.072
Durability	0.261	0.633	0.106
Ease of use	0.261	0.633	0.106
Versatility	0.106	0.261	0.633
Cost of purchase	0.309	0.581	0.110
Operational cost	0.106	0.261	0.633

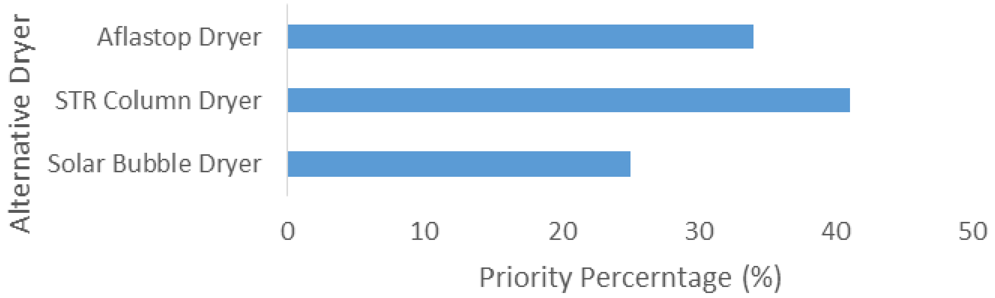

Figure 11 Global priority values of each alternative drying system

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Conflict of Interest Declarations

The authors have no interest to declare.

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