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Techno-Economic Analysis of a Crossflow Column Dryer for Maize Drying in Ghana

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Abstract: In Ghana, smallholder maize farmers continue to serve as the primary contributor to maize production. These farmers, however, still face challenges of access to appropriate, effective, and efficient drying systems. They continue to depend on open sun drying, which leads to high post-harvest losses. In this study, a 500 kg portable column dryer with a biomass burner heat source was evaluated using maize. Indicators such as drying rate, drying efficiency, and moisture extraction rate were used to assess its technical performance. The economic performance of the drying system was appraised using Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PBP). The results showed that the moisture content of maize was reduced from 22.3% to $13.4 \pm 2.6\%$ in 5 h at an average drying rate of 1.81%/h and drying efficiency of 64.7%. Utilization of the column dryer for the provision of drying services in a maize-growing community over a 10-year utilization period proved viable with an NPV and IRR of \$1633 and 71%, respectively, PBP of less than two years, and BCR of 2.82. Adoption of such low-capacity mobile grain dryers in sub-Saharan Africa would be beneficial in providing timely drying services and improve the socio-economic status of smallholder maize farmers in the region.

Keywords: biomass utilization; economic analysis; grain dryer; maize drying; technical performance



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1. Introduction

The importance of maize cannot be overlooked due to its significant role in fighting hunger and improving the socio-economic comfort of the people in sub-Saharan Africa [1]. In Ghana and many countries in sub-Saharan Africa, the crop is the most produced and consumed staple [2]. It is harvested at high moisture content, and as such, it is required that the moisture content be reduced to 12–14% to ensure safe storage for future use in humid and warm countries like Ghana [3,4].

Drying as a post-harvest activity is the most attractive method for conditioning food grains by removing moisture to a safe moisture level. This is because the drying process has proven reliable and flexible for removing moisture from food grains [5]. Although drying of food products is widely applied in various industries globally, it has been a challenge for the smallholder farmer in Ghana and other parts of sub-Saharan Africa.

In Ghana, drying of harvested maize is usually done using traditional drying methods where farmers leave the crop to dry in the field or the open sun next to farmers' homes or along roadsides, either on bare ground or on tarpaulins [2]. This reduces the quality of the dried maize grain and leads to contamination of dried food grains [6]. The situation becomes challenging when harvesting of food grains coincides with unfavorable drying weather conditions such as the rainy season, during which the drying process can take up to 5 days. Drying under such adverse conditions leads to the growth of molds [7], resulting in a considerable loss of food grains in terms of quality.

In attempts to improve the process of crop drying by reducing the drying period, lower drying cost, reliability and accessibility of drying systems, and environmental issues associated with drying, there has been the introduction of varieties of drying system such as solar dryers [8,9], biomass assisted hybrid dryers [10], and other mechanical drying systems. However, most farmers have not widely adopted these interventions, and they continue to dry their harvested produce using the unreliable and inefficient open sun drying method [4]. According to Kaaya and Kyamuhangire [11], such drying technologies are capital intensive to install and operate, making their operation expensive for the smallholder farmer to patronize.

According to Chua and Chou [12], low-cost drying systems are more suitable for smallholder farmers in developing countries. They highlighted that such drying technologies should have low initial capital cost, easy to operate with no complicated electronic and/mechanical protocol, effective in promoting better drying kinetics. The authors also reported that low-cost drying systems should also be easily constructed with available local materials and be run on renewable energy.

The economic and technical appraisal of such drying technologies is vital for their adoption by smallholder farmers. Successful assessment of these low-cost technologies drives their scale-up from research laboratories to commercialization and adoption. This study sought to assess the economic and technical performance of a portable locally fabricated half-tonne capacity column drying system with a biomass burner for maize drying in Ghana.

2. Materials and Methods

2.1. Technical Performance Study

2.1.1. Study Site

The drying experiment was conducted at the Department of Agricultural and Biosystems Engineering of Kwame Nkrumah University of Science and Technology (KNUST) in the Ashanti Region of Ghana. It is located at 06°41'5.67" N 01°34'13.87" W with average temperature and rainfall being 26 °C and 1448 mm, respectively. During the major maize harvesting period, average temperature and relative humidity conditions varies between 31 °C to 32 °C and 74% to 75%, respectively.

2.1.2. Dryer Description

The crossflow column dryer, shown in Figure 1, was fabricated at the Department of Agricultural and Biosystems Engineering, KNUST. It is a mobile drying system that can be transported from one place to another. The dryer consists of three main parts: a cylindrical drying bin, a portable biomass burner, and a fan (blower). The drying bin of 1.20 m height is made up of an inner and an outer wall cylinders that holds grains in the annular space of 0.25 m thickness. The inner and outer wall cylinders with radii 0.15 m and 0.40 m, respectively, make up the plenum and drying chamber of the dryer, respectively. Both the inner and outer wall cylinders were constructed with a perforated metal sheet to allow hot air movement across the inner bin, through the grains, and exit of moist air through the outer bin. The biomass burner serves as the primary heat-generating component of the dryer, and it is made up of heat exchangers. The burner is designed to accommodate a variety of biomass such as corn cobs, wood chippings, and rice husk. From a preliminary experiment conducted on just the biomass burner, corn cobs were fed into to burner at a feed-rate of 12 kg/h. After combustion of biomass, ashes fall through a grate in the combustion chamber for easy collection. The blower sucks air from the biomass burner through the heat exchangers and then forces the drying air through an air delivery tube to the drying bin. At the dryer's plenum, drying air is forced to pass through the drying chamber radially by restricting the movement of the drying air in the plenum by using a stopper.

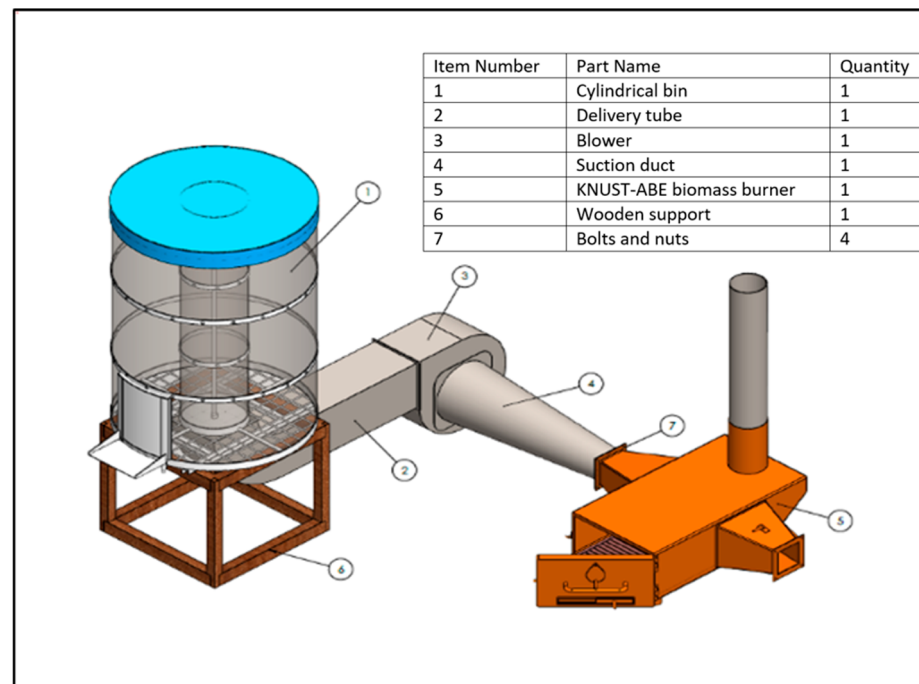


Figure 1. CAD model of the crossflow column dryer showing all of its parts.

2.1.3. Experimental Procedure

Freshly harvested maize from a local farm was used to evaluate the performance of the dryer. The initial and final moisture contents of the sample was determined using a pre-calibrated John Deere (JD) moisture meter manufactured by AgraTronix™ (Moisture Check Plus™), (SW08120, Moline, IL, USA). Temperature distribution in the dryer was monitored by temperature sensors positioned in the dryer, as shown in Figure 2. From the base of the drying bin, temperature sensors were placed at 15 cm, 30 cm, and 45 cm representing Level 1 (L1), L2, and L3, respectively. At each level (L1, L2, and L3) in the drying chamber, three different sensors were distributed radially at every level. With the use of an anemometer thermo-anemometer (Extech, Melrose, MA, USA) at the suction end of the blower, the airflow rate during the experiment was measured to be 10 m³/s.

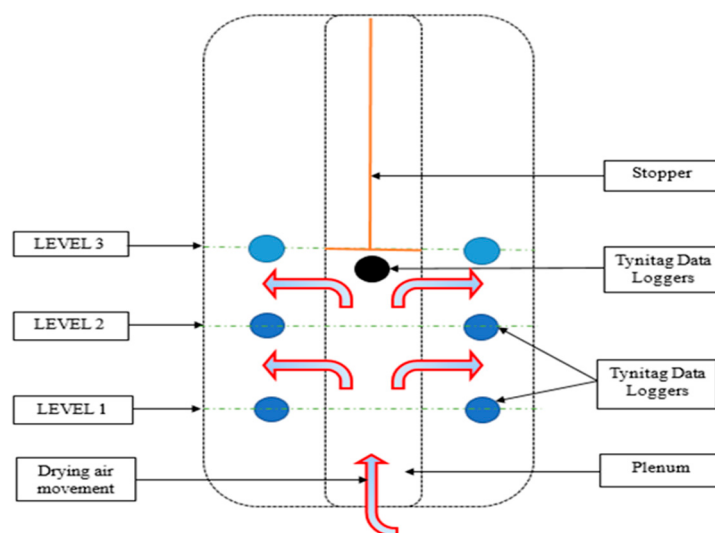


Figure 2. Longitudinal cross-section showing points of data collection.

In the process of monitoring moisture loss in the drying bin, a sampling rod was used to take maize samples from the inner and outer sections of the drying bin, at each of the drying levels as shown in Figure 3, and 70 g was taken from the sample lot for analyses. Samples were taken at all levels; L1, L2, and L3, at three different points, P1, P2, and P3. Furthermore, samples were taken from both inner and outer sections to check for moisture reduction in maize at every given point. Representative moisture content and temperature data were analyzed based on the average of the data taken at various points at each level.

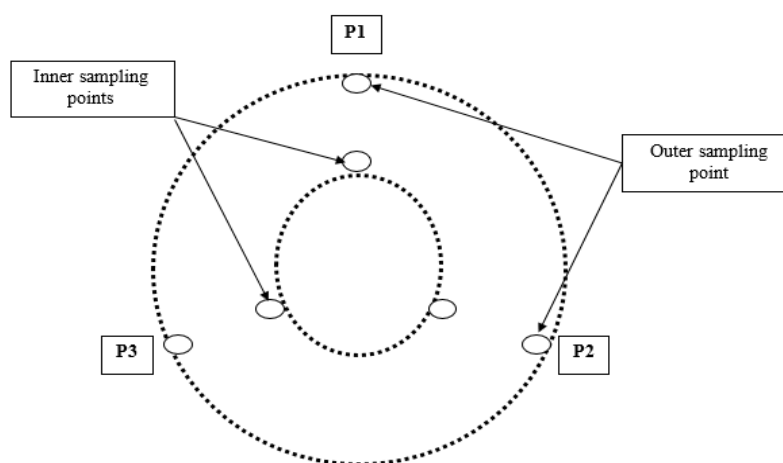


Figure 3. The transversal section of the drying chamber showing sampling points for moisture determination.

2.1.4. Dryer Performance Indices

Dryer performance indices such as drying rate, moisture extraction rate, and drying efficiency were considered for the performance assessment of the crossflow column dryer. Equations (1)–(3) show the expressions that were used to determine the performance indices.

Drying Rate, DR

The drying rate, DR, was determined using Equation (1).

$$DR = \frac{M_i - M_d}{t} \quad (1)$$

where M_i = initial moisture content (% w.b.), M_d = final moisture content (% w.b.), and t = drying time (h).

Moisture Extraction Rate, MER

Moisture extraction rate was determined using Equation (2).

$$MER = (W_i \times (\frac{M_i - M_d}{100 - M_d})) / t \quad (2)$$

where M_{ER} = moisture extraction rate (kg/hr), W_i = initial mass of grain dried (kg), M_i = initial moisture content (% w.b.) and M_d = final moisture content (% w.b.) and t = drying time (h).

Drying Efficiency, η

The drying efficiency, which gives the ratio of the energy used to evaporate moisture from the product to the energy provided by the drying air, was determined using Equation (3).

$$\eta = \frac{M_{ER} L_v}{M_{air} C_{p_{air}} \Delta T} \times 100 \quad (3)$$

where η = drying efficiency (%), M_{ER} = rate of moisture evaporation (kg/hr), L_v = latent heat of vaporization of water (kJ/kg), M_{air} = mass flow rate of air (kg/hr), $C_{p_{air}}$ = specific heat capacity of air (kJ/kg. °C) and ΔT = change in temperature between the ambient and drying air (°C).

The drying efficiency was converted in specific energy values in MJoules per kilogram of moisture removed using Equation (4).

$$\text{Specific Energy Consumption} = \frac{M_{Biomass} \times H_{Biomass}}{M_w} \quad (4)$$

where $M_{Biomass}$ = mass of biomass combusted during drying (kg), H_v = heat value of biomass (kJ/kg), M_w = mass of moisture removed from maize during drying (kg).

2.2. Economic Performance Study

The economic assessment on the column drying system was appraised from the perspective of a smallholder maize farmer using the discounted method where the time value of money is considered.

2.2.1. Case Study Scenario

The following assumptions were made for the scenario considered for the study:

1. A smallholder farmer owns the column dryer for drying maize.
2. The farmer owns/cultivates maize on a 2-ha farmland.
3. The farmer harvests 1.5 t/ha of maize as estimated by the Ministry of Agriculture [13] in Ghana.
4. The farmer uses the column dryer to dry all his/her maize.
5. The farmer provides drying services to other maize farmers in his community.

The model scenario outlay is shown in Figure 4.

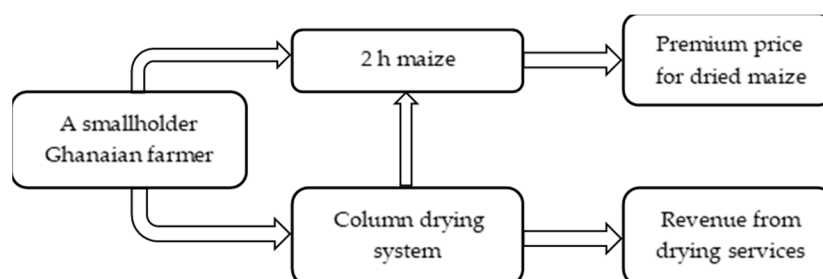


Figure 4. Schematic description of the model scenario considered in the study.

2.2.2. Estimation of Cost and Revenue

The cost component was made up of the investment cost and cost of operation and maintenance. The investment cost consisted of all the expenses required to set up the complete drying system. This included the cost associated with the fabrication of the drying column, biomass burner, and an electric blower. The cost of electricity for operating the drying system during operation and a flat rate of 2% of equipment and machinery cost was assumed to be operation and maintenance costs, respectively. The cost of fuel, which comprised of the cost of corn cobs, was not considered since the biomass residue is anticipated to be readily available in the study area. The revenue generation stream was sourced from the price charged for providing drying services to other farmers in the community. The drying charge and quantity of maize anticipated to be dried were presented in the economic model to determine the annual total revenue generated.

2.2.3. Economic Appraisal

Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period were used to evaluate the economic performance of the column dryer.

NPV uses a discounting method for evaluating the economic viability of the investment and gives the value of all future cash flows in today's currency. This provides a true measure of an investment's economic feasibility. It presents the present value of cash in and outflows [14]. A positive NPV indicates an economically viable investment or project, while a negative one shows that it is not economically feasible to carry out such investment or project [15]. Equation (5) was used to calculate the NPV.

$$NPV = \sum_{t=0}^N a_t S_t \quad (5)$$

where S_t = net cash flow at a specific time (t), N = number of years (10 years), and a_t = financial discount factor, which was calculated using Equation (6).

$$a_t = \frac{1}{(1+i)^t} \quad (6)$$

where t = time from 0 and 10 years and i = the discount rate (%).

IRR is the discount rate that makes the net present value of all cash flows from a particular investment equal to zero. Generally, the higher the IRR, the more desirable it is to undertake the project [16]. IRR was determined using Equation (7).

$$NPV = \sum \frac{S_t}{(1+IRR)^t} = 0 \quad (7)$$

PBP is the number of years it takes to recover an investment's initial cost. It provides a simple way to assess the economic merit of investments. Equation (8) was used to calculate the PBP.

$$PBP = \frac{C_i}{S} \quad (8)$$

where C_i = initial investment cost and S = net cash flow

BCR is the ratio of total discounted benefit to total discounted cost. Projects with a benefit-cost ratio greater than 1 have greater benefits than costs; hence, they have positive net benefits. The higher the ratio, the greater the benefits relative to the costs. It was calculated using Equation (9) [17].

$$BCR = \sum (B_i / (1+d)^i) \div \sum (C_i / (1+d)^i) \quad (9)$$

where B_i = benefit of the project in year i ($i = 0$ to 10 years), C_i = cost of the project in year i , and d = discount rate.

2.2.4. Financial Assumptions

The following financial assumptions were made during the assessment:

1. Cash flows were discounted over a ten-year period based on the expected useable lifetime of the Crossflow Column Dryer.
2. An operation period of three months per year is considered since the major harvest season starts in June/July and ends in August/September. This harvesting period coincides with the rainy season, making maize drying a challenge for a typical maize farmer in Ghana.
3. The dryer is expected to be operated at 500 kg full capacity.
4. The dryer will be operated by the farmer, and as such, no cost for labor is expected for operating the dryer.
5. A discount rate of 14%, which is Ghana's discount rate of February 2019 [18], was used for the analysis.
6. A percentage of 2% of the investment cost was assumed to be maintenance cost in the financial analysis.

2.2.5. Sensitivity Analysis

Sensitivity analysis was carried out by varying one parameter of the economic model and determining the effect of that change on the economic indicators. Analysis of such sort is needed to measure the effect of changes in critical variables of investments on the economic indicators [14,19]. The critical variables considered for the sensitivity analysis included:

1. Discount rate variation: Discount rate is one of the key variables that determine the NPV of investments. The analysis was made using a 7%, 14%, 21%, and 28% discount rate. The basis for considering these variations was based on the variation of discount rate in Ghana since 2000 [18], which has witnessed minimum and maximum values of 12.5% and 27.5%, respectively.
2. Drying prices of \$0.75, \$0.94, \$1.13, and \$1.32 per bag of maize were considered for the analysis. The drying price was varied from \$0.75 to \$1.32 per bag of maize. These drying prices are lower than the least price charged for drying maize by other installed mechanical drying facilities in most farming communities in Ghana, which is about \$ 2.80.
3. The investment cost, which consists of setting up the complete drying system, was also varied to determine its effect on the viability of the case scenario. This was done because it is anticipated that any investor who may deal in the manufacture and distribution of the column drying system would want to gain profit by selling the dryer at a higher price than the estimated investment price. Increments were made at 20%, 50%, and 80% more of the base investment cost.

3. Results

3.1. Technical Performance Evaluation

3.1.1. Temperature Variation during Drying

Temperature variation in the plenum and the drying chamber, compared to the ambient during the drying process, is shown in Figure 5. The plenum temperature increased steadily from 38 °C to a maximum of 58 °C within the 5 h drying period. This resulted in a corresponding increase in the air temperature in the drying chamber from 35 °C to a maximum of 44 °C during the same period. Average temperatures of 51.5 ± 4.8 °C and 38.5 ± 2.8 °C were recorded at the plenum and drying chamber of the column dryer, respectively. The mean temperature in the drying chamber was 9 °C higher than the ambient temperature.

As a common phenomenon with column drying systems, there was not much difference in the drying air temperatures at different levels, L1, L2, and L3, as shown in Figure 6. In the drying chamber, average temperatures of 39.4 ± 2.3 , 36.1 ± 1.2 and 39.9 ± 2.5 °C were recorded at L1, L2, and L3, respectively. A similar observation was made by Alam et al. [20] and Kumar et al. [21], who worked on the performance of a column drying system where there were no substantial differences in temperatures between the top, middle, and bottom sections of the drying chamber.

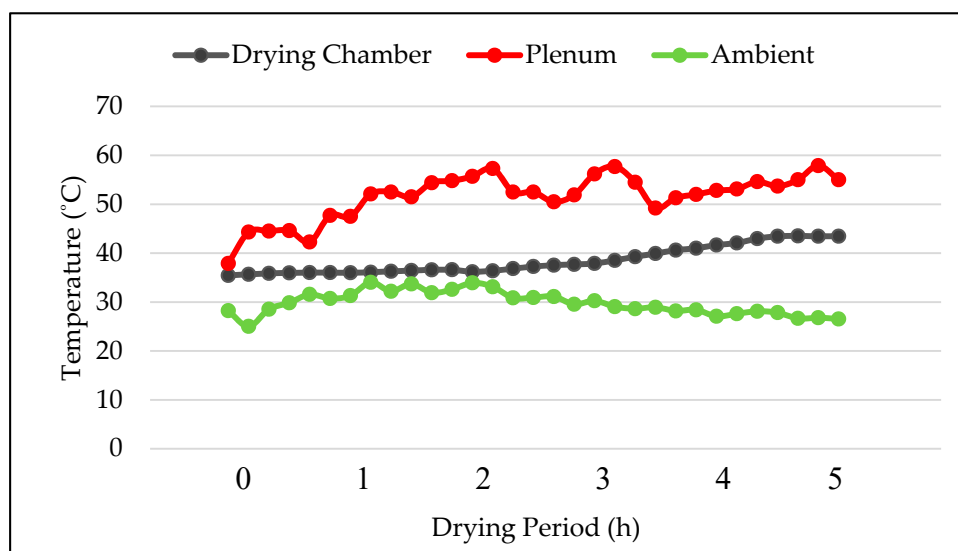


Figure 5. Temperature variations in the plenum and drying chamber during the experiment.

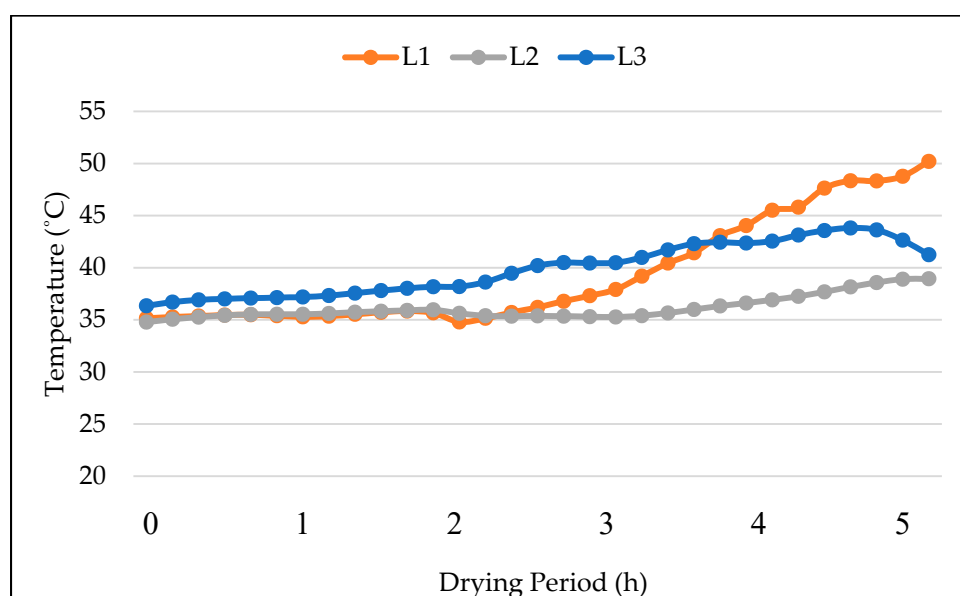


Figure 6. Temperature variations at L1, L2, and L3 in the drying chamber.

3.1.2. Moisture Content Variation During Drying

The variation in moisture content at the inner and the outer sections of the column dryer during the drying experiment is shown in Figure 7. The grain moisture content decreased with drying time, with grains closer to the plenum (inner section) reaching a lower moisture content after 5h of drying compared to grains close to the outer edge of the drying column (outer section). The drying process occurred in the falling rate period, as shown in Figure 7, where the moisture content of maize decreased from 22.3% wet basis (w.b.) to $11.6 \pm 0.3\%$ and $15.4 \pm 0.3\%$ for grains at the inner and outer sections, respectively, within the 5 h drying period.

Variations in the moisture content of grains sampled transversally across the drying chamber could be attributed to variation in the drying air temperature. It is forced through the drying bed with all the grains not fully exposed to the same drying air condition which is established by plenum. As demonstrated in Figure 8, the grain mass at the inner section of the dryer is exposed to drying air of high temperature compared to the grain mass at the outer section. As drying air moves from the plenum across the mass of maize, moisture

is lost from the grains to the drying air, thereby increasing the humidity of the drying air along the transversal depth of the maize grains towards the outer section. According to Chakraverty and Singh [22], this is a common phenomenon in deep bed dryers, which leads to grains at the inner section drying faster compared to grains at the outer section.

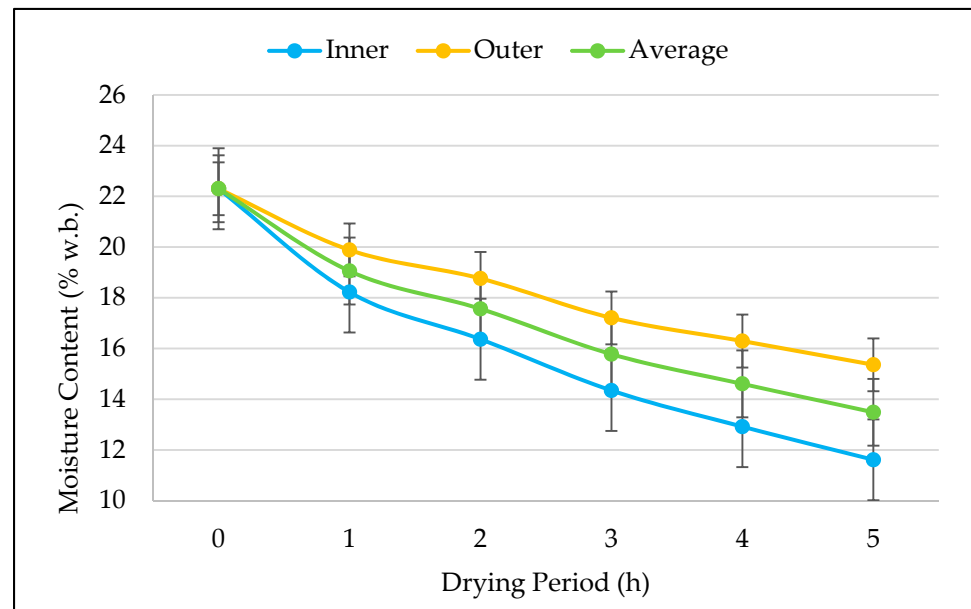


Figure 7. Moisture content variation with time at the inner and outer sections of the dryer.

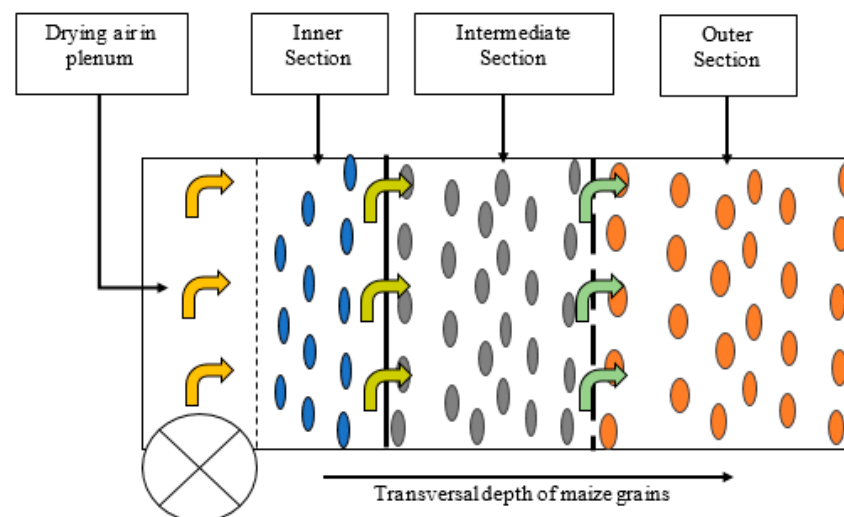


Figure 8. Schematics of the deep bed drying principle.

The findings of this study are corroborated by Kumar et al. [21]. They made similar observations in moisture content variations of wheat and maize grains dried in a similar deep bed dryer. The final moisture content of dried samples was 10.76% and 10.84% for the inner and outer sections, respectively.

The moisture contents of maize grains at different levels L1, L2, and L3, as shown in Figure 2, along the longitudinal depth at the inner and outer sections of the dryer was analyzed. The analysis of MC of grains across the longitudinal depth at both the inner and outer section of the dryer did not vary significantly, as shown in Figure 9. Grains at different levels at both the inner and outer sections for the drying chamber reached $11.6 \pm 0.3\%$ and $15.4 \pm 0.3\%$ moisture contents, respectively.

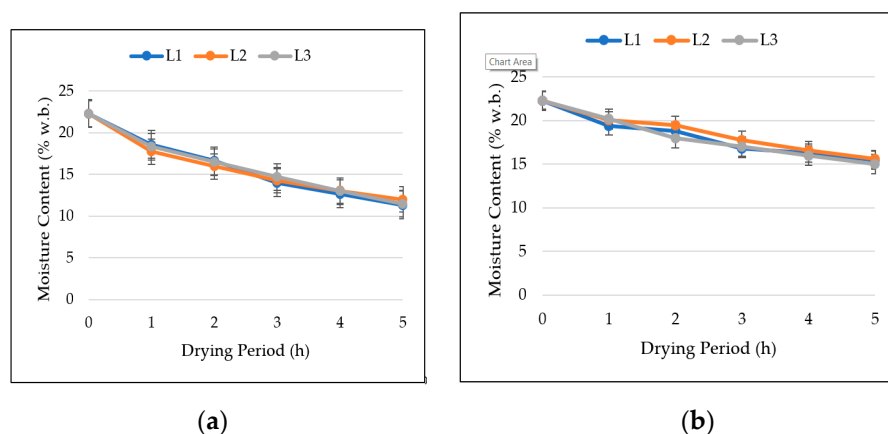


Figure 9. Variation of moisture contents at L1, L2, and L3 at the (a) inner section of the drying chamber; and (b) outer sections of the drying chamber.

To ensure that maize dried in a column dryer reaches the safe moisture content of about 13% (w.b.) before storage in tropical weather conditions like Ghana, Kaaya and Kyamuhangire [11] recommend that thorough mixing of grains close to the inner and outer sections during unloading should be encouraged.

3.1.3. Dryer Performance Specification

Table 1 shows the column dryer's technical performance, which satisfies the drying needs of smallholder maize farmers. The average temperature distribution of 38.5 ± 2.8 °C in the drying chamber was not too much of a drying temperature that can result in the loss of seed viability [2,23,24]. This is an essential consideration for adopting grain dryers as about 80% of smallholder grain farmers rely on their seed stock from their previous harvest [2,25]. Hence, using dryers that tend to reduce the seed viability of their harvest, usually due to high drying temperatures of 70–100 °C, should be avoided. More so, the designed capacity of the grain dryer matches the harvesting rate of grain farmers, making the column dryer suitable for adoption by grain farmers [12].

Table 1. Summary of dryer technical performance.

Parameter	Value
Dryer	
Initial mass of maize	250 kg
Initial moisture content	22.3%
Final moisture content	$13.3 \pm 2.6\%$
Average drying time	5h
Average drying rate	1.8%/h
Drying Efficiency	64.7%
Specific energy consumption	9.23 MJ/kg of moisture
Average Drying Temperature	38.5 ± 2.8 °C
Average MER	5.1 kg/h

3.2. Economic Performance Evaluation

3.2.1. Technical and Financial Analysis of the Drying System

Table 2 presents the financial and technical parameters considered for the operation of the dryer for the case scenario. Based on a drying capacity of 500 kg of maize per batch, it is expected that two batches of drying could be achieved per day. Performance study of the drying system shows that a farmer can dry his maize from an initial moisture content of about 22% (w.b.) to a safe moisture content of 13% (w.b.) within a period of 5 h. This translates to a 720-h operational period of three months from June/July to August/September. This period happens to be the time when over 60% of Ghana's maize

produced in the major production season by smallholder farmers along the transition belt of Ghana is harvested. Drying services are critically needed during this period as the harvesting period normally coincides with the onset of rains used for the minor season maize cultivation. Based on the dryer's specified capacity and the drying time, it is estimated that 72 tonnes of maize (554 bags) are expected to be processed within the operational period of three months in a year.

Table 2. Technical and financial parameters considered for the business model proposed in the study.

Parameter	Value
Capacity of drier (kg)	500
Number of batches per day	2
Number of hours required per batch of drying	5
Number of operational days per week	6
Number of operational hours per week	60
Number of operational months per year	3
Operational hours per year (h)	720
Quantity of maize per bag (kg)	130
Number of bags of maize dried per day	8
Number of bags dried of maize per week	46
Quantity of maize dried per year (t)	72
Number of bags of produce processed per year	554
Estimated amount of crop produced per year in the district (t)	20,000
Number of dyers required to process the total available maize	278
Lifespan of drying system (years)	10
Price charged for drying a bag of maize (\$)	0.94

Furthermore, according to MoFA-SRID [13], most smallholder maize farmers in Ghana cultivate an estimated average farmland size of 2 ha at an average yield of 1.5t/ha, correspond to 3 tonnes of maize produced by a farmer in a cropping season. This quantity of maize is projected to be dried within three operation days of the dryer. This means the dryer would be available to other smallholder maize farmers who otherwise will use the unreliable open-sun method for drying their maize. In that regard, about 24 smallholder maize farmers ($72 \text{ tonnes of maize} \div (2 \text{ ha/smallholderfarmer} \times 1.5 \text{ tonnes of maize/ha})$), therefore, could rely on the dryer for their drying services within the operational period used for the case scenario.

3.2.2. Cost and Returns on Investment

The initial capital cost for the complete drying system is presented in Table 3. The main cost component, as shown in Table 3, is the fan cost, estimated to be 46.9% of the total investment cost.

Table 3. Capital cost of the drying system.

Investment	Cost Value (USD)	% of Total Investment Cost
Column dryer plus auxiliary units (air delivery ducts)	189.00	31.3
Biomass Burner	132.00	21.9
Blower (Fan)	283.00	46.9
Total Fixed Cost	604.00	100.0

The costs associated with the operation and maintenance of the dryer are presented in Table 4. An amount of \$12 representing 2% of the total investment cost is allocated for maintenance and overhead expenses. With a fan of a motor rating of 0.75 kW, a total power of 540 kWh required per an operation cycle, an amount of \$82 is estimated as the cost of electricity for the operation of the drying system. The cost of electricity was estimated at \$0.15 per kWh in Ghana [26].

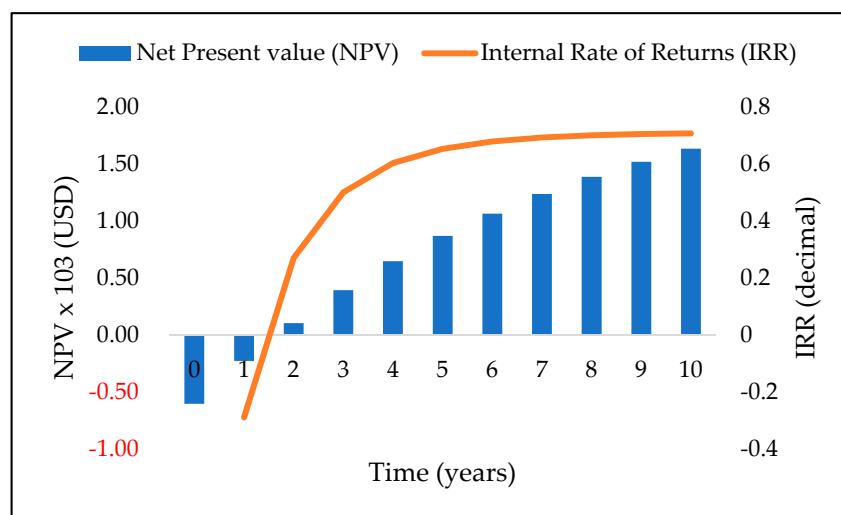
Table 4. Operation and maintenance cost of running the drying system.

Operations and Maintenance	Cost Value (USD)/Operation Cycle
Maintenance and overhead expenses (2% of investment cost)	12.00
Cost of electricity	82.00
Total running/variable Cost	94.00

At a projected six days of operation per week for the three-month operational period per year, it is expected that the column dryer will be used to dry 72,000 kg of maize per year. At a drying price of \$0.94 charged per bag (130 kg) of maize to be dried, total revenue of \$523 is anticipated since 554 bags of maize will be dried during the operation cycle of three months in a 12-month year.

3.2.3. Economic Appraisal of the Business Model

For the case scenario considered in the study to be financially viable, Abbood et al. [15] reported that an NPV of a positive value and an IRR greater than the present interest rate (14% for the case study) should be targeted. The variation of the NPV and IRR over the operation period is presented in Figure 10. Economic analysis of the case scenario revealed that, at a discount rate of 14% over a projected 10-year lifespan of the drying system, an NPV and IRR of \$1633 and 71%, respectively, can be achieved at a payback period of 1.41 years after operations begin. The economic indicators' values prove the viability of the case scenario where a farmer can invest in owning and running the column dryer as a business in the study area. The study results agree with studies by Adams et al. [14] and Mensah et al. [27], who worked on the financial feasibility of a mango-chip processing and small-scale meat production, respectively, in Ghana. In their studies, the authors reported the economic viability of their case studies in Ghana, where there were similar trends in NPV and IRR for the operational period of the individual startups.

**Figure 10.** Variation of NPV and IRR over the 10-year operation period.

3.2.4. Sensitivity Analysis

The effect of price variations for maize drying (\$/bag of maize) on the economic outlook of the case scenario is presented in Table 5. The analysis of the results shows that at a constant discount rate of 14%, the NPV, IRR, and BCR values increased considerably at an increased cost of drying. For instance, at 20% increase in drying charge from \$0.94 to \$1.13, the NPV increased by 33% (from \$1633.00 to \$2174.00). A similar increasing trend was observed for the other economic indicators as IRR and BCR increased by 24% and 20%, respectively. However, the PBP decreased by 20% when the drying price was

increased by 20%. This indicates that an investor will regain his investment in a relatively shorter time as the price charged for drying maize is raised, and more revenue is expected. However, a reduction of the drying price also showed a reverse effect on the economic indicators seen in Table 4. Similar results have been reported by Abbood et al. [15], who worked on the financial analysis of a 1 MW PV plant, and observed that NPV and IRR increased considerably with an increase in the selling price of electricity. The result shows that variations in the cost of maize drying using the drying system can affect the economic potential of the business model.

Table 5. Variation of NPV, IRR, PBP, and BCR with drying price charged per bag (130 kg) of maize.

Drying Charge (USD/Bag of Maize)	NPV (\$)	IRR (%)	PBP (years)	BCR
0.75	1084	53	1.86	2.26
0.94	1633	71	1.41	2.83
1.13	2174	88	1.13	3.39
1.32	2723	106	0.95	3.96

The effect of discount rate on the economic indicators at a constant drying price of \$ 0.94 per bag of maize was also investigated, and the result is presented in Table 6. The analysis shows that when the discount rate increases, the economic viability of the business model tends to be affected negatively with respect to the NPV and BCR and vice versa. For instance, with a 50% increase in the discount rate, from 14% to 21%, NPV and BCR decreased by 31% and 17%, respectively. On the other hand, PBP and IRR were not affected by variations in the discount rate. This is attributed to the independence of both economic indicators on the discount rate reported by Abbood et al. [15].

Table 6. Variation of NPV, IRR, PBP, and BCR in relation to the discount rate.

Discount Rate (%)	NPV (\$)	IRR (%)	PBP (years)	BCR
7	2409	71	1.41	3.47
14	1633	71	1.41	2.83
21	1135	71	1.41	2.34
28	798	71	1.41	1.98

The final sensitivity analysis was done in anticipation of manufacturers, investors, and/or distributors who may sell or distribute the drying system. The study considered a situation where an operator tends to buy the column drying system from a manufacturer or an investor at a cost that is 20%, 50%, and 80% more than the actual manufacturing cost (investment cost). The profit margins on the investment cost of the dryer were simulated at a drying charge of \$ 0.94/bag and using a discount rate of 14%. The reflection in the economic indicators is presented in Table 7 to see their effect on the economic indicators. NPV, IRR, and BCR tend to decrease as the profit margin on the investment cost increases, although PBP increases. This is justified since a higher investment cost means an extended period to break even on an investment. Although the economic feasibility of the case scenario tends to decline in values, even at a higher profit margin of 80% increase on the investment cost, the economic indicators demonstrate a viable case with a positive NPV and IRR of \$1100 and 37%, respectively.

Table 7. Variation of NPV, IRR, PBP, and BCR in relation to increasing dryer cost.

Estimated Investment Cost (USD)	NPV (\$)	IRR (%)	PBP (years)	BCR
604 (base cost)	1633	71	1.41	2.83
725 (20% more)	1500	58	1.70	2.54
906 (50% more)	1300	46	2.14	2.21
1089 (80% more)	1100	37	2.59	1.95

4. Conclusions

The techno-economic performance of a half-tonne capacity crossflow column dryer with a biomass burner heat source was successfully assessed. Maize at 22.30% was dried to a final moisture content of 13.25% within a period of 5 h. The average drying rate recorded during the study was 1.81%/h with a drying efficiency of 64.65%. The economic viability of a case study was assessed to be viable for a smallholder maize farmer or an investor who operates a unit to provide drying services to maize farmers. The economic analysis over a 10-year lifespan operation of the dryer resulted in an NPV of \$1633 and IRR of 71%. At an assumed drying charge of \$0.94/bag, which is one-third lower the drying charges of a typical commercial drying facility in Ghana, an investor is expected to recoup his investment in the shortest possible time at a PBP of 1.48 years with a BCR of 2.55. Finally, the positive performance indicators provide confidence for scale-up and adoption by smallholder maize farmers in Ghana. It is recommended that manual mixing of grains should be incorporated in the unloading of maize from the drying system to minimize the difference in moisture content between the grains at the inner and outer sections. Smallholder grain farmers should adopt portable and mobile, low-cost grain drying systems in Ghana and sub-Saharan Africa. In order to facilitate this adoption, smallholder farmers should be brought the knowledge of the technical and economic performance of these systems. In addition to this, smallholder farmers should be equipped with entrepreneurial skills to better utilize such technologies for economic benefits and provide on-time drying services to mitigate the substantial loss of grain in most rural grain-growing communities in sub-Saharan Africa.

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