



Techno-economic analysis of a biomass-powered inclined bed dryer for maize drying

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ABSTRACT

The study assessed the technical performance and economic viability of a 200 kg capacity biomass-powered inclined bed dryer for drying maize. The dryer recorded an average air temperature of 73.54 °C in the plenum, which reduced the moisture content from 23.25% (w.b) to 13.61% (w.b) at a drying time of 2 hours 40 minutes. This resulted in a drying rate, drying efficiency, and specific energy consumption of 9.50 kg/h, 71.37%, and 25.70 MJ/kg, respectively. The germination potential of dried maize grains was 80% compared to 93% for grains assessed before drying. Stress-crack analysis revealed a lower percentage of no-cracks for dried maize (71%) than maize gains before drying (98%). There was a statistically significant difference between the dried and the undried maize grains for germination viability ($p = 0.01$) and stress crack analysis ($p = 0.00$) at $\alpha=0.05$. At a drying charge of US\$ 2.4 per 100 kg bag of maize, the investment cost could be regained at a pay-back period of 6 months and 15 operation days and a benefit-cost ratio of 1.27. The drying system is economically viable at net present value of US\$ 1313.48 and internal rate of return of 44%. Evidently, adopting the dryer could contribute to reducing post-harvest loss of maize at the smallholder level and increase farmer's income.

Keywords: Maize drying, Technical performance, Grain quality, Economic viability

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Introduction

Maize is a staple food crop in Ghana, constituting about 50% and 60% of annual cereal production (Darfour and Rosentrater, 2016). Maize is produced mainly by farmers at the small-scale level mostly in the agro-ecological zones using rudimentary hand tools such as a hoe and cutlass under traditional tillage, rainfed conditions, and sunlight-dependent drying methods (Amanor-Boadu, 2012; Darfour and Rosentrater, 2016).

In Ghana and several other African countries, maize is typically harvested at moderately high moisture content, in a range of 18.7% to 26.8% wet basis (AGRA, 2013). After harvesting, it is stored in humid and mild and humid condition (Alborch *et al.* (2012) reported that grains with high temperature and moisture content are

susceptible to deterioration and development of insect pests and fungal infection growth. For this reason, grains are dried immediately after to optimum moisture content to maintain grain value and quality at storage. According to Barnwal and Tiwari (2008), drying crops contributes to longer shelf life, higher product quality, and a decrease in postharvest loss, hence, ensuring food security.

The open sun drying method has drawbacks due to the dependence on sunlight, long drying period, and rainfall interruption, which results in slow drying rates and non-uniform drying (El-Sebaii and Shalaby, 2012). A typical example is maize drying by smallholder farmers in the transition zone in Ghana, where the harvest



period after the major production season of maize coincides with rainfall and interrupts drying activities. Diesel and liquefied petroleum gas-powered dryers are relatively expensive and hence have high drying charges. This makes it necessary to develop a cost-effective and user-friendly mechanical drying technology for smallholder farmers, particularly in developing economies in sub-Saharan Africa. This is reiterated by [Chua and Chou \(2003\)](#), who reported that smallholder farmers in developing nations are better suited for low-capacity drying systems. They stated that these drying systems have low investment costs, are easily operable without requiring complex protocols, and effectively improve drying kinetics. Based on this, a biomass-powered inclined bed dryer was designed and fabricated using local materials.

The biomass-powered inclined bed dryer provides continuous drying even under bad weather conditions like cloudy and rainy periods to ensure proper drying of maize. [Apotei \(2019\)](#) reported that biomass fuel sources are cheap, available, and accessible in Ghana, making the use of a biomass-powered dryer a highly feasible and potentially cost-effective method of drying maize for smallholder farmers. Techno-economic assessment of such low-capacity dryers is vital for their scale-up and adoption. Such analysis could lead to commercializing research and laboratory prototypes to marketable products. This study, therefore, sought to assess the technical and economic performance of a prototype inclined bed dryer with a biomass energy source for maize drying in Ghana.

Materials and Methods

Study area

The study was conducted at the Department of Agricultural and Biosystems Engineering, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. The study area is located at 6°415 'N and 1°34 'W in latitude and longitude, respectively.

Dryer description

The biomass-powered inclined bed dryer was designed and fabricated at the Department of Agricultural and Biosystems Engineering, KNUST. The drying system consists of three (3) main components, namely: combustion chamber, blower unit, and drying chamber.

The combustion chamber consists of a fuel inlet, heat exchanger, heat exchanger housing, and a chimney. During combustion, the heat exchanger becomes heated, and a blower unit sucks heated air within the pipes into the plenum of the dryer. The blower connects and directs the heated air from the heat exchanger in the combustion chamber to the plenum (Fig. 1). The blower unit is fitted with wire mesh to prevent the passage of foreign materials into the drying system. The drying chamber consists of a plenum, a 7° inclined removable drying bed made of 3 mm mild steel bars, and a transparent Perspex sheet housing with vents (Fig. 1). The dryer bed is rectangular (2.5 m length, 1.3 m width, and 0.15 m depth). At the lower end of the dryer bed is the outlet for offloading. The inclination of the dryer bed additionally allows easy offloading of the maize through the exit after drying.

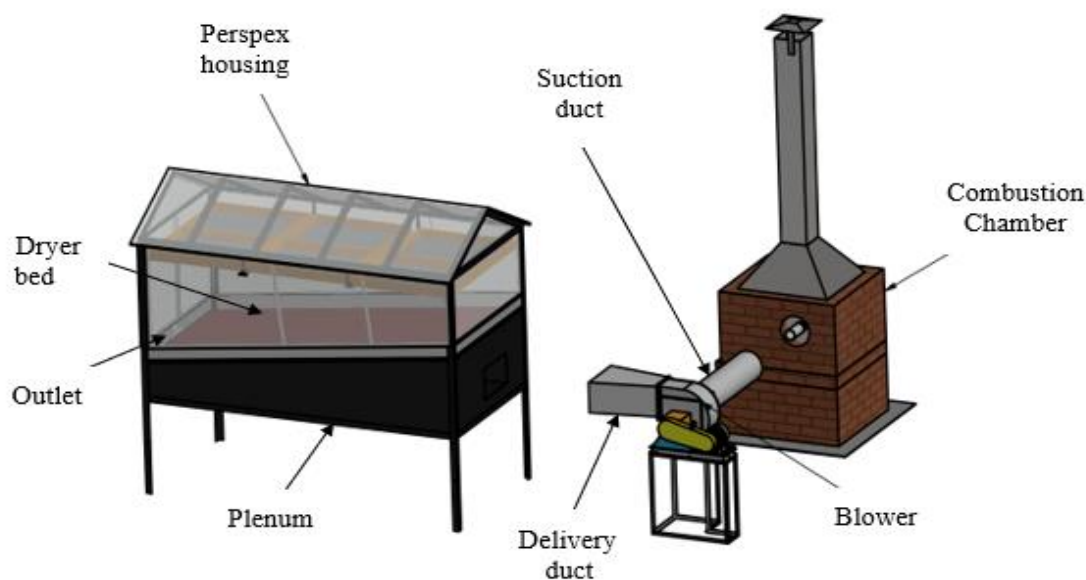


Fig. 1. Schematic illustration of the biomass-powered inclined bed dryer.

Experimental procedure

The performance of the biomass-powered inclined bed dryer was evaluated using freshly harvested yellow maize (*Honampa* variety) with predetermined moisture content from KNUST Agricultural Research Station Farm at Anwomaso. 200 kg of maize was measured using a weighing scale, poured, and spread over the dryer bed to ensure uniformity. The moisture content of the drying maize was determined three (3) times at every 20 minutes intervals until the ultimate moisture content was obtained at 13 to 14% (w.b). The temperature in the drying system was determined at 10 min intervals using the temperature sensors (Tinytag plus 2 data logger, TGP-4520) (Fig. 2). The drying experiment was repeated in three (3) replicates. The temperature sensors were fitted under the dryer bed at the lower (L), middle (M), and upper (U) part of the bed to measure the temperature along the width and length of the dryer bed.

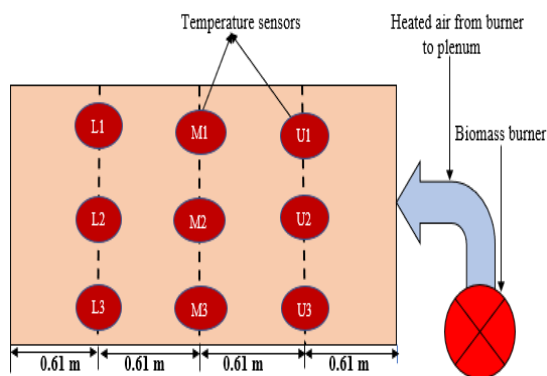


Fig. 2. Temperature sensors under the drying bed.

Dryer performance indices

The technical performance of the drying system was evaluated using indices such as burner efficiency, moisture extraction rate, drying rate, drying efficiency and specific energy consumption.

Burner efficiency

Burner efficiency (BE) of the dryer was calculated using Equation (1):

$$BE = \frac{M_{air} \times CP_{air} \times (T_{air} - T_{amb})}{M_{bc} \times H_v} \times 100 \quad (1)$$

Where, M_{air} = mass flow of air (kg/h), H_v = heat value of dry bamboo (kJ/kg). T_{amb} = ambient temperature ($^{\circ}C$), T_{air} = temperature of hot air from the combustion chamber ($^{\circ}C$), CP_{air} = specific heat capacity of air (KJ/Kg. $^{\circ}C$), and M_{bc} = feed rate of the biomass (Kg/h).

Moisture extraction rate

Moisture extraction rate (MER) was calculated from Equation (2):

$$MER = \frac{W_i \times \left(\frac{M_i - M_f}{100 - M_f} \right)}{t} \quad (2)$$

Where, M_i = initial moisture content of maize grains (% w.b), W_i = Initial mass of maize grains (kg), and M_f = final moisture content of maize grains (% w.b).

Drying rate

Drying rate (DR) was calculated from Equation (3):

$$DR = \left(\frac{M_w}{dt} \right) = \frac{m_i - m_f}{t} \quad (3)$$

Where, DR = drying rate (kg/h), M_w = change in mass (kg), dt = change in time (h), m_i = initial mass of maize grains (Kg), m_f = final mass of maize grains (kg), and t = drying time (h).

Drying efficiency

Drying efficiency, η (%) was determined from Equation (4):

$$\eta = \frac{M_w L_v}{M_{air} C_{p,air} \Delta T} \times 100 \quad (4)$$

Where, M_w = moisture evaporation rate (kg/h), ΔT = temperature difference between the drying air and ambient ($^{\circ}C$), and L_v = Latent heat of vaporisation of water (kJ/kg).

Conversion of drying efficiency to specific energy consumption (SEC) values in MJ/Kg of removed moisture was calculated using Equation (5).

$$SEC = \frac{M_{Biomass} H_{Biomass}}{M_w} \quad (5)$$

Where, M_w = Removed moisture during drying of maize grains (kg), $M_{Biomass}$ = combusted mass of biomass (kg), and $H_{biomass}$ = heat value of biomass (kJ/kg).

Grain quality assessment

Stress crack analysis

Stress Crack Index (SCI) was calculated using Equation (6):

$$SCI = (1 \times SC) + (3 \times DC) + (5 \times MC) \quad (6)$$

Where, SC = single crack, DC = double cracks, and MC = multiple cracks

Germination analysis

After determining the number of germinated seeds, Equation (7) was used in calculating the germination percentage:

$$\%G = \frac{(\% \text{ of number seeds germinated})}{(\% \text{ of number seeds set for germination})} \quad (7)$$

Where, G = germination

Economic performance of biomass-powered inclined bed dryer

The cash flow model was used as the study approach for the economic analysis of the biomass-powered inclined bed dryer.

Cost and revenue estimation of the dryer

The cost estimation of the dryer includes the cost incurred in the construction and purchase of dryer components and operation and maintenance costs. The operation and maintenance cost consisted of electricity for powering the blower unit and a 2% operation and maintenance cost for equipment and machinery. Biomass fuels such as corncob and bamboo were freely available and accessible in the study location.

The source of the project's annual total revenue envisaged is the drying charge of maize for smallholder maize farmers.

Economic analysis

The cash flows were evaluated using economic indices such as Benefit-Cost Ratio (BCR), Net Present Value (NPV), Pay-back Period (PBP) and Internal Rate of Return (IRR). The economic analysis of the biomass-powered inclined bed dryer was performed under the financial presumptions as follows; Based on the estimated lifetime of a biomass-powered inclined bed dryer, cash flow was discounted over 10 years. The economic assessment was conducted using Ghana's discount rate of 24%, as of January 2022 (Bank of Ghana, 2022). The financial assessment estimated that maintenance costs were 2% of the investment cost (Obeng-Akrofi *et al.*, 2021).

Economic indices

The following economic indices were used in assessing the economic performance of the biomass-powered inclined bed dryer;

Net present value

A positive NPV implies a financially viable investment, whereas a negative one suggests that such an investment or project is not economically viable (Gittinger, 1982). NPV is calculated from Equation (8):

$$NPV = \sum_{t=0}^N atSt \quad (8)$$

Where, S_t = net cash flow at time (t), N = number of years (10 years), and at = the financial discount factor.

The financial discount was determined from Equation (9):

$$at = 1/(1+i)^t \quad (9)$$

Where, t = the time between 0 and n , i = the discount rate

Benefit-cost ratio

The drying system is economically feasible only when the Benefit-Cost Ratio (BCR) is more than one (Gittinger, 1982). BCR was calculated from Equation (10):

$$BCR = \sum_{i=0}^n \left(\frac{Bi}{(1+d)^i} \right) \div \sum_{i=0}^n \left(\frac{Ci}{(1+d)^i} \right) \quad (10)$$

Where, Bi = project benefit in year $i=0$ to n , Ci = project cost in year i , d = discount rate.

Internal rate of return

The dryer is profitable when the Internal Rate of Return (IRR) exceeds the attractiveness rate, thus minimum acceptable return percentage required for the use of the drying system to be profitable (Baum and Tolbert, 1985). The IRR was calculated from Equation (11):

$$NPV = \sum_{t=0}^n St(1+IRR)^t = 0 \quad (11)$$

Pay-back period

Pay-Back Period (PBP) is the period taken for the cumulative revenues to cover the initial investment.

$$PBP = \frac{Ci}{S} \quad (12)$$

Where, C_i = initial investment cost, and S = net cash flow

Sensitivity analysis

Sensitivity Analysis was done to determine the effect of varying variables of the generated model terms of NPV and IRR. The following considerations were made;

Variation of the discount rate. Discount rate (t) is a major parameter determining the project's NPV. Discount rates increment of 10% and higher, and 10% lower than the current discount rate was evaluated.

Due to price fluctuations throughout the year, from season to season, the drying price for a bag of maize increases and decreases.

Results and Discussion

Technical performance of the biomass-powered inclined bed dryer

Temperature variation in the dryer

The temperature of drying maize increased as the temperature of the drying air in the plenum increased. The drying air temperature and the maize temperature were in the range of 65.12°C – 81.63°C and 28.40°C – 52.10°C throughout the drying period, with average temperatures of 73.54°C and 43.92°C, respectively (Fig. 3). An average drying air temperature of 73.54°C ±

5.74 °C was recorded in the plenum, compared to an ambient temperature of 28.42 °C ± 1.76 °C, indicating 45.12 °C temperature difference. The temperature of the drying air was higher than the temperatures obtained by [Kaaya and Kyamuhangire \(2010\)](#) and [Akowuah *et al.* \(2021b\)](#), who reported mean temperature of drying air of 52.8 °C and 52.4 °C, respectively, on maize drying from biomass heat source.

The drying maize temperature recorded an average temperature of 43.92 °C, which increased with an increase in drying air temperature. The fluctuation in the grain temperature was attributed to the fluctuation in the temperature of the drying air due to restocking of biomass fuel, and continuous stirring of the grains. Similar results was reported by [Obeng-Akrofi *et al.* \(2021\)](#) in the study of maize drying in a column dryer utilizing a biomass heat source.

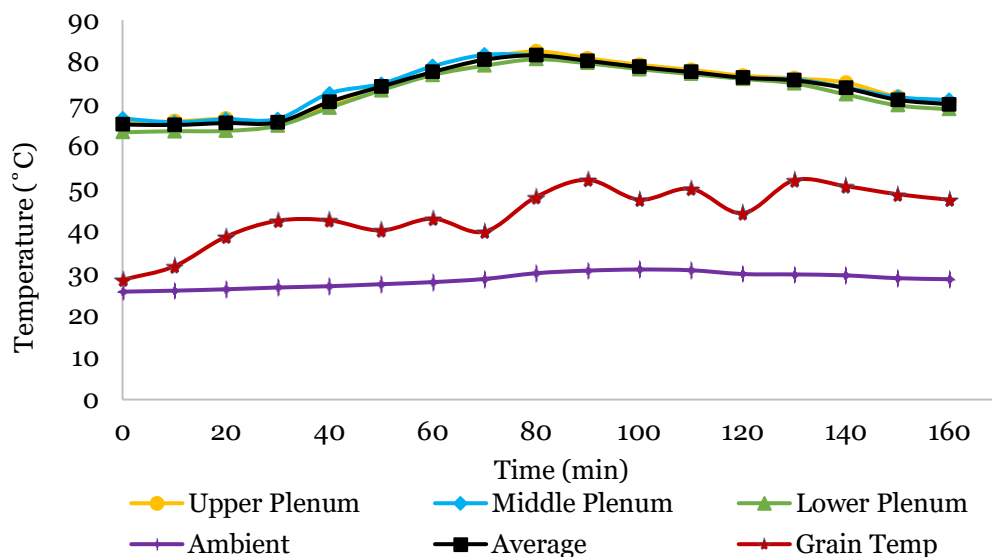


Fig. 3. Temperature distribution in the drying system.

The average temperature at the upper, middle and lower parts of the bed was 73.98 ± 0.14 °C, 74.17 ± 0.47 °C, and 72.49 ± 0.75 °C, respectively, indicating near-even temperature distribution.

airflow distribution across the dryer bed was high in the middle and the extreme ends of the drying bed. Low airflow was only observed at the vertex of the plenum close to the blower exit.

Fig. 4 shows the temperature gradient distribution and airflow in the plenum. The

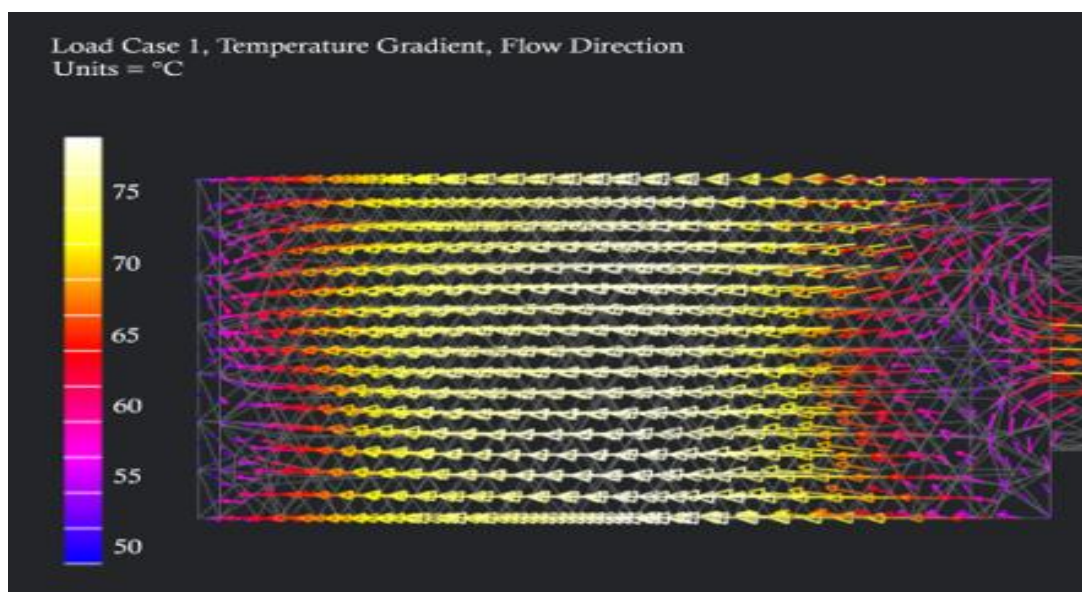


Fig. 4. Simulation of heated airflow in the plenum.

Moisture variation of maize

The moisture content of the maize grains decreased with time during the drying process, and this cured in the falling rate period (Fig. 5). After 2 h 40 min, the moisture content of the maize decreased on average from 23.25% ± 0.02% (wb) to 13.61% ± 0.13% (wb).

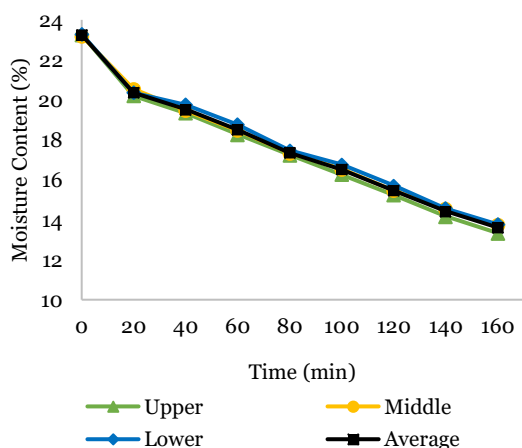


Fig. 5. Moisture content against drying time.

The moisture content of the maize grains at the upper, middle, and lower parts of the drying bed largely decreased from 23.25% (wb) to 20.20 ± 0.12% (wb), 20.53% ± 0.11% (wb), and 20.37% ±

0% (wb), respectively during the first 20 min of the drying experiment. This is observed as a steep slope on the moisture content versus the time graph in Fig. 5. The moisture content decreased with time in a near-linear trend until it reached a safe moisture content of 13.33% ± 0.20% (wb), 13.73% ± 0.09% (wb), and 13.77% ± 0.11% (wb) for maize at the upper, middle, and lower part of the drying bed, respectively. The results are in congruence with Owusus-Sekyere *et al.* (2021) and Obeng-Akrofi *et al.* (2021), who also reported similar observations in their study involving maize drying in an AflaStop and a column dryer, respectively.

Summary of the technical performance of the dryer

The drying system recorded an average plenum drying air temperature of 73.54°C from the biomass burner with an efficiency of 42.4% which was used to dry maize from an initial moisture content of 23.25% ± 0.02% (wb) to 13.61% ± 0.13% (wb) within 2 h 40 min. The maize was dried at an average moisture extraction rate and drying rate of 6.70 kg/h and 9.50 kg/h, respectively. The drying efficiency was recorded as 71.37%.

Table 1. Technical performance evaluation of the biomass-powered inclined bed dryer.

Parameters	Values
Dryer capacity	200 kg
Drying temperature	73.54 °C ± 5.74 °C
Initial MC (w.b)	23.25% ± 0.02%
Final MC (w.b)	13.61% ± 0.13%
Drying time	2 h 40 min
Drying rate	9.50 kg/h
Moisture extraction rate	6.70 kg/h
Drying efficiency	71.37%
Specific energy consumption	25.70 MJ/kg
Burner efficiency	42.40%

Grain quality assessment

Germination viability assessment

The germination analysis showed that maize grains before drying recorded higher germination percentage (93.33%) compared to the dried maize grains (80%) (Fig. 6). There was statistically significant difference at p-value of 0.01 (α=0.05) for germination viability between the dried maize and the undried maize grains. The results were in line with Bajus *et al.* (2019), who recorded germination potential of 93% and 74% for maize drying using heated air-drying temperatures of 50 °C and 70 °C, respectively.

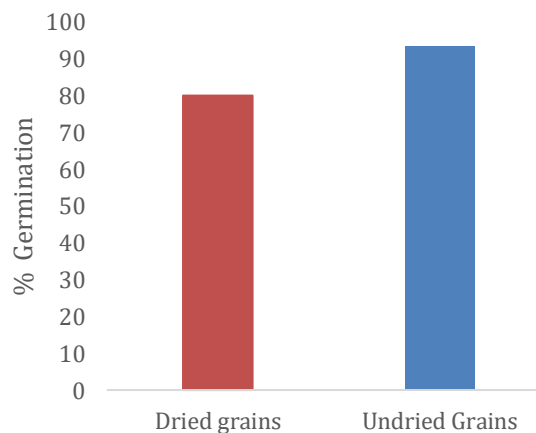


Fig. 6. Percentage germination of maize.

Stress crack analysis

Analysis of stress cracks showed that zero cracks recorded for maize grains before drying was 97.67% compared to 71.33% for maize grains after drying in the dryer (Fig. 7). Only 2.33% of undried maize grains had single cracks. The dried maize subjected to single, double, and multiple cracks recorded respective percentages of 14.33%, 8.67%, and 5.67%. A stress crack index of 68.7 was recorded for dried maize grains and 2.3 for undried grains before the drying experiment.

There was a statistically significant difference at $p=0.00$ ($\alpha=0.05$) for stress crack analysis between the dried and undried maize. Thus, the heated drying air affected the breakage susceptibility of the maize, as reported by Davidson *et al.* (2000).

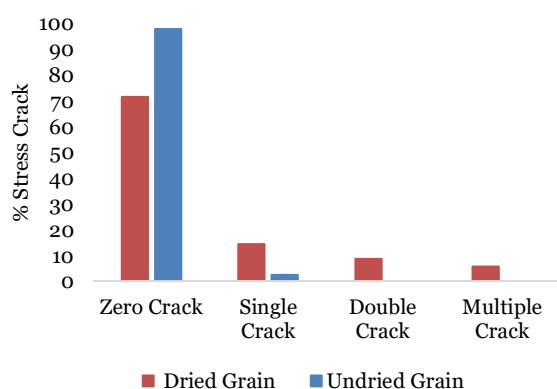


Fig. 7. Percentage stress crack of dried and undried maize.

Economic assessment of the drying system for maize drying

Technical and financial analysis of the drying dryer

Table 2. Technical and financial parameters for dryer operation.

Parameters	Value
Capacity of the dryer (tonnes)	0.2
Operating months per year	3
Number of drying batches per day	4
Time (hours per drying batch)	3
Operational month per year	3
Quantity of produce dried per year (tonnes)	58
Estimated quantity of maize produce at Ejisu Municipal District (tonnes)	48,054
Number of dryers required to dry maize produced at Ejisu Municipal District	834
Direct employment generated by the total number of dryers (persons)	834
Lifespan of dryer (years)	10
Drying price per bag of maize (US\$)	2.4
Cost of purchasing one bag of dried maize (US\$/100kg)	58.33
Percentage of maize lost without using the dryer	15
Monetary value of post-harvest loss prevented (US\$)	4,608

For a 0.2 tonnes capacity dryer that can dry maize to a safe storage moisture content of 13.61% (wb) (Fig. 5) within 3 h, it is estimated that the dryer can operate 4 batches of drying in a day (Table 2). This can meet the drying needs of smallholder farmers in Africa who, according to Nuss and Tanumihardjo (2010), do not cultivate more than 0.7 ha of land per year. Considering 3 operational months (July to September) after maize harvesting in the major production season along the transition zone in Ghana, the dryer could dry 58 tonnes of maize when in operation. Based on the current estimated maize production of 48,054.48 tonnes in the study area as reported by (MoFA, 2020), it is estimated that 834 dryers would be required to meet the drying demand in the study locality, providing jobs for 834 individuals who would operate the dryers.

For US\$ 2.4 drying charge per bag of maize (100 kg) and US\$ 58.33 selling price per bag of maize, it is remunerative to patronize maize drying using the drying system. Because of the 15% post-harvest loss of maize due to improper drying in the Ejisu Municipal District, as reported by MoFA (2020), it is estimated that the use of the dryer would prevent postharvest loss of maize in monetary value of US\$ 4,608.

Cost and return on investment analysis

The investment cost consisted of the total cost of the drying unit, blower unit, and biomass combustion unit, amounting to US\$ 2,000. Analysis of the results shows that the dryer unit constitutes the highest cost (46.67%) of the total initial investment cost, followed by the biomass combustion unit (30%) and the blower unit (23.33%) (Table 3).

A total of US\$ 573.01 was estimated for the operation and maintenance cost per the operation cycle of 3 months for the dryer. It was estimated that 70.37% of the operation and maintenance cost was allocated as wages for a laborer who will operate and control the drying process during the 3 months, 17.43% for maintenance and overhead expenses, and 12.18% of the cost of electricity.

For a drying charge of US\$ 2.4 per 100 kg bag of maize and an estimated 576 bags of maize to be dried per each drying cycle in a year (3 months) (Table 3), it is estimated that the operation of the dryer will generate US\$ 1,382.4 in the first drying cycle of operation.

Table 3. Cost analysis of the dryer.

Parameters	Value (US\$)	Percentage cost (%)
Investment cost		
Dryer component	933.3	46.67
Blower unit	466.6	23.33
Biomass combustion unit	600	30.00
Total	2,000.00	100
Operation and maintenance cost		
Maintenance and overhead expenses (2% of the investment cost)	100.00	17.45
Cost of paying for labourer	403.20	70.37
Electricity cost (dryer operation)	69.81	12.18
Total	573.01	100

Economic assessment of the dryer

Economic analysis of the business model showed that the Net Present Value (NPV) increased from a negative US\$ 2,000 to a negative US\$ 1,347.27 after 1 year (3 months) of operation. This was due to the partial settlement of the investment cost from the discounted net cash flow of US\$ 652.73.

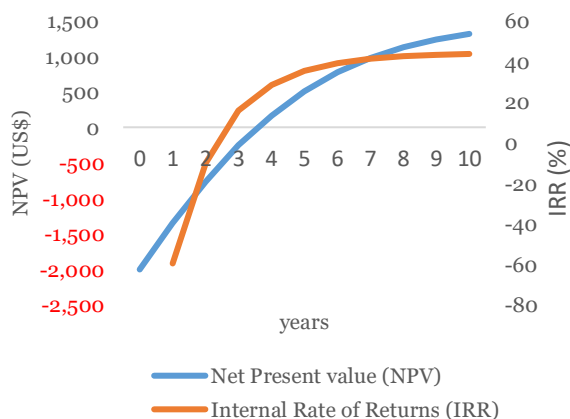


Fig. 8. Variation of NPV and IRR over 10 years operation period.

From Fig. 8, the NPV increased from a negative US\$ 2000 to a positive US\$ 1313.48, with a corresponding increase in the Internal Rate of Return (IRR) from negative 60% to positive 44%

over the 10 years. A positive NPV (US\$ 1313.48) and IRR (44%) greater than the discount rate (24%) indicate that it is financially rewarding to invest in the biomass-powered inclined-bed dryer for maize drying as reported [Santana *et al.* \(2019\)](#) and [Akowuah *et al.* \(2021a\)](#).

Furthermore, the analysis showed a Pay-back Period (PBP) of 2.26 years (6 months and 15 operation days) and Benefit-Cost Ratio (BCR) of 1.27. Thus, it will take 2.26 years to recoup the investment cost while delivering an NPV at a rate of 1.27.

Sensitivity analysis of the business model

The drying price and discount rate were two variables that influenced the economic viability of the biomass-powered inclined bed dryer for maize drying. Analysis of the variation of the price of drying a bag of maize on the NPV, IRR, PBP and BCR at 24% discount rate (Table 4). At US\$ 2.4 drying charge per bag of maize, the results revealed that an increase in the drying price (10% increase) increase the NPV, IRR, BCR, and decreased the PBP, and vice versa. The results were in line with [Abbood *et al.* \(2018\)](#), who reported a change in NPV and IRR with variation in electricity cost.

Table 4. Variation of drying price on NPV, IRR, PBP, and BCR.

Drying Price US\$/Bag of maize	NPV (US\$)	IRR (%)	PBP	BCR
2.13	696.36	35	2.84	1.14
2.40	1313.48	44	2.26	1.27
2.64	1,932.73	52	1.88	1.40
2.90	2,609.43	60	1.59	1.54
3.19	3,356.83	79	1.35	1.69

Analysis of variation of the discount rate on NPV, IRR, PBP, and BCR at a fixed drying price of US\$ 2.4 (Table 5). The discount rate during the experiment was 24%. From the analysis of the results, it is anticipated that an increase in the (10% increase) discount rate would decrease the

NPV and BCR, and vice versa. The IRR and PBP remain constant in both cases. This is because the period and rate at which the project would regain the investment cost are independent of the discount rate.

Table 5. Variation of Discount Rate on NPV, IRR, PBP and BCR.

Discount (%)	NPV (US\$)	IRR (%)	PBP	BCR
19.44	1,842.92	44	2.26	1.34
21.60	1,575.98	44	2.26	1.31
24.00	1,313.48	44	2.26	1.27
26.40	1,081.59	44	2.26	1.23
29.04	856.49	44	2.26	1.19

Conclusion

The drying system recorded an average drying air temperature relatively higher than the ambient temperature to facilitate a shorter drying time. The biomass-powered inclined bed dryer is suitable for maize drying by drying maize from an initial average moisture content of 23.25% ± 0.02% (w.b) to 13.61% ± 0.13% (wb) at a drying rate, drying efficiency, and specific energy consumption of 9.50 kg/h, 71.37%, and 25.7 MJ/kg of moisture, respectively. However, when using the dryer for drying grains for seed, the amount of biomass feedstock input should be regulated to reduce the input temperature. The biomass-powered inclined bed dryer for maize drying by smallholder farmers is economically viable at a positive NPV of US\$ 1,313.48, IRR (44%) greater than the discount rate (24%), and pay-back period of 2.26 years (6 months and 15 operation days) cost at BCR of 1.27. Adoption of the biomass-powered inclined bed dryer in the study location is estimated to prevent post-harvest loss of maize in a monetary value of US\$ 4608 while providing jobs for 834 youths to operate the expected number of dryers required to meet the drying needs of smallholder maize farmers at Ejisu Municipal District.

The adoption of the biomass-powered inclined bed dryer for maize drying would provide a reliable, cost-effective, and financially rewarding method of drying maize, which would consequently reduce postharvest loss of maize and ensure food security in Ghana.

Acknowledgement

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