

Techno-Economic Assessment of a Rotatable Fish Grill for Charcoal and Briquette

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ABSTRACT

Charcoal and briquette fuel material were each assessed for use in a locally manufactured rotatable fish grill. Fresh African Catfish (*Clarias gariepinus*) samples averagely weighing 500 ± 54 g were taken from a fishpond managed under a recirculating aquaculture system (RAS) at the study location. Three repetitions of a Completely Randomized Design (CRD) were used, and LSD was calculated at $p \leq 0.05$. The findings indicate that compared to briquette fuel material, charcoal used much more energy. Similarly, grilling using charcoal required much more time (53 minutes) than grilling with briquettes (37 minutes). The energy efficiency of the grill did not differ significantly between charcoal (93.6%) and briquette (92.9%). Similarly, no significant difference in specific fuel consumption was observed for charcoal (1.06) and briquette (0.90) fuel material. Fish grilled over charcoal or briquette produced cooking yields of 72% and 70%, respectively. Breakeven for charcoal and briquette assuming the grill is under a custom hiring arrangement was estimated at 1010.9 hours and 991.83 hours, respectively. Future studies should examine organoleptic evaluation of fish grilled on rotatable grills to determine whether the finished product is acceptable to consumers. Nile Tilapia (*Oreochromis niloticus*) could be the subject of a similar investigation.

Keywords: grilling, rotatable fish grill, fuel material, grilling time, breakeven hour

INTRODUCTION

One of the most consumed foods and an essential part of the human diet is fish. Fish is the primary source of animal protein consumed by humans [1]. Benefits of fish include its high protein content, ease of digestion, and low-fat level [2]. OECD/FAO (2011) predicted that the global demand for fish would rise across all continents by 2020 and reach 17.9 kg per person. According to current estimates, 90% of fish production will be used as food, and by 2029, fish for human consumption is expected to rise by 16.3% [4]. Approximately 81% of the fish produced worldwide is for human consumption. This growing demand is a result of consumers' favourable perceptions of fish as nutritious foods with benefits to human health [3].

Before being consumed, fish is frequently exposed to several treatments. Processed fish accounts for a sizeable portion of daily dietary intake for people. A product is processed to create its nutritional and sensory qualities as well as to eradicate infections, germs, and parasites (Kondjoyan, et al. 2015). Manuela et al. (2012) defined processing as the art of

transforming raw ingredients into consumable food. The appearance, flavor, aroma, shape, and color of the food are changed or altered by the application of engineering technology and food science. On a grill, which employs dry heat to cook food, fish is one of the most popularly prepared dishes. The popularity of grilling sets has increased recently, and grill makers are continually attempting to develop grills that can rapidly and safely prepare food like fish while preserving its flavor. This recent change in the narrative may be related to a deeper understanding of the advantages of grilled fish over fried fish in terms of both health and economics. This is demonstrated by the sudden increase in "Catfish point and kill" eateries in all of Ghana's main cities and communities. There are numerous different types of grilling equipment that are utilized all around the world. These include of grills, portable grills, grill netting, and electric grills [7]. These appliances and grill layouts all have limitations. Previous mechanisation research intervention in fish processing focused on some preservation methods other than grilling (Odiko & Abolagbo, 2015; Michael et al., 2019; Ajewole et al., 2021). Notably, Fasakin et al., (2009) developed a model rotatory fish smoking kiln using agro-wastes as source of fuel. Similarly, Ashaolu (2014) developed and assessed the performance of a motorized fish smoking kiln in Nigeria. Amponsah et al. (2022) recently characterized a locally developed kiln using charcoal and briquette for smoke-drying Catfish processing. In general, research information on fish grilling process in the African context is currently non-existent. Engineering and science must fill the void caused by the acute absence of technical and economic information on this grilling equipment used locally.

Local craftsmen in Ghana construct grill machines out of an old iron foundation with stands and an empty fuel drum that has been poorly welded together after being longitudinally machined into two pieces. These grilling appliances waste energy and produce smoke. Grilling fish products that are charred poses several health dangers due to excessive heat radiation [14]. Fish contamination occurs when it is treated to high-temperature treatments like grilling, according to Ishizaki and Saito (2010). Fish contaminated with heavy metals has led to significant worries about both food safety and human health [16]. Due to the necessity of often flipping fish on locally constructed grills with bare hands, both the user and the consumer run the risk of suffering serious injuries. This is because it is possible to handle fish with dirty hands. Local engineers have created a simple, rotational grill that allows for rapid lighting and heating of the fuel material without generating any pollutants or blowing ashes into the food being cooked. Users of the rotatable grill should have the chance to improve their energy efficiency, timeliness, environmental safety, user safety, and consumer safety. To give potential users more accurate information and speed up the adoption process, the aim of this study was to assess the efficiency of this rotating grill from a technical and economic aspect.

Specifically, the study sought to:

1. calculate the energy efficiency, specific fuel consumption, and energy expended by the grill for charcoal and briquette fuel material.
2. determine the grilling time and cooking yield of grilling fish using charcoal and briquette.
3. assess the economic feasibility of the rotatable grilling machine for charcoal and briquette fuel materials.

MATERIALS AND METHODS

Experimental Site

The study was carried out in September 2022 at the Cottage on the grounds of the CSIR-Crops Research Institute, Fumesua near Kumasi, Ghana.

Description of the Rotatable Grill

The rotating grilling machine (Figure 1) is made up of a grilling grate with a lock, flip handle, fuel box, fuel box mount, grill stand, and height adjustment lever. Technical specifications of the rotatable grill are specified in Table 1. The grilling grate features a mechanical lock that prevents fish from falling while rotating. The grilling grate can be rotated using a cylindrical-shaped wooden handle that is fastened to metal supports at the ends. The fuel box moves on a movable mount in the grilling machine platform, and the movement of the mount is controlled by a turning handle.

Table 1. Technical specifications of the rotatable fish grill

Parameter	Specification
Dimension of grilling machine (L × B × H)	1066 mm × 558 mm × 762 mm
Weight of machine (under no-load)	10.5 kg
Estimate capacity	6 kg
Dimension of Charcoal chamber (L × B × H)	660 mm × 444 mm × 101 mm
Dimension of rotatable grilling grate (L × B × H)	660 mm × 457 mm × 38 mm
Material used for construction	Galvanized steel sheet and mild steel angle
Insulation material used	Wood



Figure 1. The rotatable fish grill.

Sample Collection and Fish Preparation

A recirculating aquaculture system (RAS) pond built up at the study location provided the African catfish (*Clarias gariepinus*) samples, which were freshly captured and used for the investigation. Harvested fish were carefully placed in a salt solution to kill fish and remove slime and scales. Samples of fish were cleaned and marinated using customary ingredients. An electronic scale was used to weigh the entire fish after it had been secured in the double-layered grilling grate (Figure 2). (FB 300 kg digital electronic scale). The fuel material was weighed each time before being added to the fuel box, and the findings were recorded. After being ignited, fuel material from the fuel box is transferred into the fuel box mount. Every twenty minutes, temperatures were recorded at the combustion chamber, above the grilling grate, and in the surrounding areas of each rotational grilling machine. A stopwatch, an infrared thermometer gun (Raytek-Raynger MX4+), and a stopwatch were used to record the readings and time the operations. The fish was placed on the grilling grate upside down to guarantee a uniform spread of heat. The height adjustment lever was used to move the fuel box closer to or further away from the grilling grate to change the temperature. Per fuel type (charcoal, briquette), three rotatable grilling equipment were used for the research.



Figure 2. Catfish sample on the rotatable grill

Performance Parameters

The operation of the rotatable grilling equipment using the two fuel types (briquettes and charcoal) was assessed based on relevant performance criteria. The grilling machine's energy efficiency was determined, along with the amount of time it took to cook, the rate at which it cooked, the amount of energy consumed, the amount of food produced, and the amount of fuel utilized.

Specific Fuel Consumption:

Equation 1 was used to calculate the specific fuel consumption (SFC), which was generated from [17]

$$SFC = \frac{\text{Total mass of fuel consumed (kg)}}{\text{Total mass of grilled (kg)}} \quad (1)$$

Energy Efficiency:

Using the expression in Equation 2 derived from, [18] the energy efficiency of the grill for charcoal and briquette fuel material was computed.

$$\text{Energy efficiency} = \frac{T_{cc} - T_{out}}{T_{cc} - T_{amb}} \times 100 \quad (2)$$

Where:

T_{amb} = Mean ambient temperature (outside)

T_{cc} = Mean inlet air temperature (combustion chamber)

T_{out} = Mean outlet air temperature (above the grilling grate)

Energy Expended:

The energy expended in grilling with charcoal and briquette was calculated using expression in Equation 3 by [19]

$$E_d = E_f \times M_f \quad (3)$$

Where:

E_d – Energy expended in drying (MJ)

E_f – Energy in fuel material (MJ/kg)

M_f – Total weight of fuel material used (kg)

E_f for charcoal and briquettes were 31.8 MJ/kg [20] and 24.7 MJ/kg [21], respectively.

Cooking Yield:

Using the formula presented by, (Bainy et al. 2015) the cooking yield of fish that was grilled over charcoal and briquettes was determined.

$$\text{Cooking yield (\%)} = \frac{\text{cooked weight of grilled fish}}{\text{raw weight of grilled fish}} \times 100 \quad (4)$$

Time Spent in Grilling:

The time spent in grilling fish was calculated using Equation 4 derived from Davies et al. (2012).

$$\text{Time spent in grilling (hkg}^{-1}\text{)} = \frac{\text{Total time spent in grilling (h)}}{\text{Total weight of grilled fish (kg)}} \quad (5)$$

Economics Assessment

The total fixed (ownership) and total variable (operating) expenses were considered to calculate the cost of grilling with the rotatable grilling machine for each fuel material (Hunt 1983). Equation 6 shows how to calculate the straight-line method of depreciation for the rotatable grilling machine, while Equation 7 shows how to calculate interest on equipment ownership.

$$\text{Depreciation} = \frac{\text{Purchase price} - \text{salvage price}}{\text{Economic life}} \quad (6)$$

$$\text{Interest} = \frac{\text{Purchase price} - \text{salvage price}}{2} \quad (7)$$

Table 2 provides the mathematical assumptions for the relevant cost items used in estimation of ownership and operating the rotatable grilling machine.

Table 2. Assumptions for relevant cost items

Cost item	Assumption	Reference
Salvage	10% of Purchase Price	Hanna (2001)
Interest	5% on principal	Hunt (1983)
Insurance	0.5% of Purchase Price	Hunt (1983)
Tax	0% of Purchase Price	Hunt (1983)
Shelter	0.5% of Purchase Price	Hunt (1983)
Repairs and maintenance	5% of purchase price	Hanna (2001)

Cost of fuel was determined as a combination of fuel material used (kg), fuel cost (GH/kg), and fuel efficiency (%). The anticipated revenue and break-even period were computed based on the total cost calculated and the assumed hiring cost, using the methodology proposed by (Fairhurst 2012).

Experimental Design and Statistical Analysis

The study used a completely randomized design (CRD) with three replicates, and the sole factor was the kind of fuel (briquettes or charcoal). GenStat statistical package version 11 was used to conduct Analysis of Variance (ANOVA) on the data set that was gathered [26]. For a p-value < 0.05, the Least Significant Difference (LSD) between treatment means was calculated.

RESULTS AND DISCUSSION

Figure 4 depicts the energy used by the charcoal and briquettes during the grilling operation. Charcoal and briquette fuel materials required 115 MJ and 73 MJ of energy per unit of fuel, respectively.

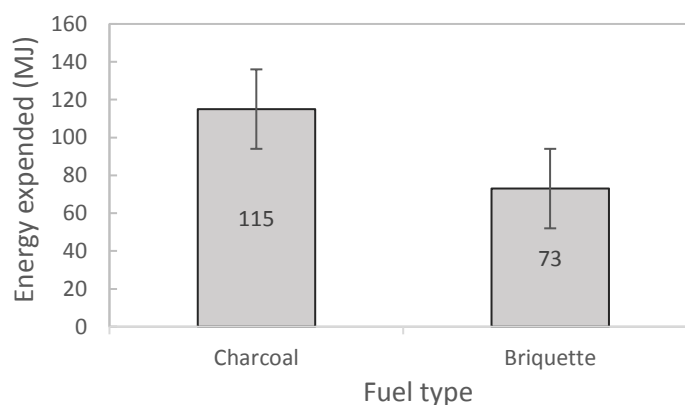


Figure 4. Energy expended by charcoal and briquette fuel material.

As a result of briquette's ability to absorb moisture and its uniform composition and particle sizes, which promote wearing and a high level of conditioning (Onukak et al. 2017), the energy required to burn a briquette is substantially lower than that required to burn a piece of charcoal.

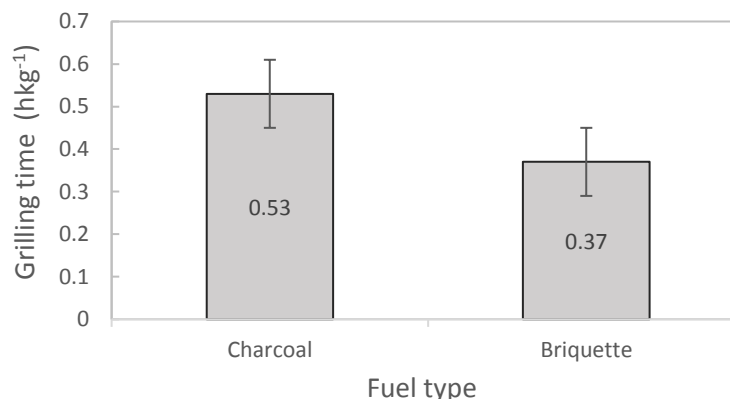


Figure 5. Grilling time for charcoal and briquette fuel materials in the grilling machine

Table 3 presents the comparative summary of statistical analysis on performance parameters for charcoal and briquette fuel materials in the rotatable grill. The use of charcoal in the grill offered a higher energy efficiency than briquette but the difference was not statistically significant. The specific fuel consumption (SFC) for charcoal was higher than briquette in grilling process but was not statistically significant.

Table 3: Statistical analysis summary on performance parameters for charcoal and briquette

Fuel type	SFC	Energy efficiency (%)	Energy expended (MJ)	Time spent (h/kg)
Charcoal	1.06±0.13	93.61±1.88	115±13.99	0.53±0.42
Briquette	0.9±0.12	92.92±1.43	73±8.75	0.37±0.01
LSD	ns	ns	12.9	0.155

Figure 5 depicts the grilling duration for briquettes and charcoal in the grilling equipment. For charcoal and briquette, the process's effective grilling times were 0.53 h/kg and 0.37 h/kg, respectively. Briquette grilling time was considerably shorter than that of charcoal. This may be explained by the fact that briquettes are made from a mixture of sawdust, rice husk, coconut husk, palm kernel shell, and starch additives that make ignition and burning more manageable [27] As a result, briquettes can be used for grilling more quickly than charcoal. The rotatable grill's comparative performance characteristics for charcoal and briquette fuel are shown in Table 4. To grill 6 kilograms of catfish on the rotatable grill, you will need 2.96 kg of briquettes and 3.6 kg of charcoal, with a cooking yield of 72% at an average grilling temperature of 58°C and 70% at an average grilling temperature of 63°C, respectively. [28] defined an outstanding yield as one that is around 90%, and a fair yield as one that is around 50%. [29] noted that poorer cooking yields are caused by interior temperatures around 800C. For charcoal and briquette, the process's actual grilling times were 53 minutes and 37 minutes, respectively.

Table 4: Performance characterization of the rotatable grill for charcoal and briquette fuel

Fuel material	Quantity of fuel used(kg)	Max. temperature (°C)	Min. temperature (°C)	Grilling duration (min)	Cooking yield (%)
Charcoal	3.6±0.44	78.7±12.6	31.3±2.4	37±0.16	72±0.74
Briquette	2.96±0.35	81.9±5.8	31.7±4.04	53±0.78	70±2.86

Table 5: Assumption for breakeven analysis

Parameter	Charcoal	Briquette
Total fixed cost (GH¢)	487.5	487.5
Total variable cost (GH¢/h)	0.02	0.01
Working hours(minimum)	50	50
Hiring cost (GH¢/h)	0.5	0.5

In general, there was a direct correlation between the costs of using charcoal or briquettes in the rotatable grilling equipment. In contrast to charcoal, briquette appears to be a more economically viable fuel material according to the prevailing assumptions. According to the findings, briquettes might be used as an alternate fuel source for all fish grilling operations to dispel the widespread belief that burning fuelwood to manufacture charcoal significantly contributes to deforestation [30]. Figure 7 proves that the rotatable grilling machine's break-even point with charcoal is at 1010.9 hours and 991.83 hours with briquettes.

Table 6: Cost analysis summary for rotatable grill using charcoal or briquette.

Cost item	Charcoal	Briquette
Purchase price (GH¢)	1000	1000
Salvage value (GH¢)	100	100
Economic life (y)	2	2
Fixed Cost (US\$/y)		
Depreciation	450	450
Interest	27.5	27.5
Insurance	5	5
Tax	0	0
Shelter	5	5
Total Fixed Cost	487.5	487.5
Fuel cost (GH¢/kg)	6	3
Fuel Consumption (kg)	3.6	2.96
Fuel efficiency (%)	0.9361	0.9292
Cooking yield (%)	72	70
Working hours/y	1500	1500
Smoking kiln capacity (kg)	6	6
Time spent (h/kg)	0.53	0.37
Worker's wage (GH¢/h)	2	2

Number of workers	1	1
Variable cost (GH¢/h)		
Fuel	20.22	8.25
Repairs & Maintenance	0.03	0.03
Labour	6.36	4.44
Total Variable Cost (GH¢/h)	0.02	0.01

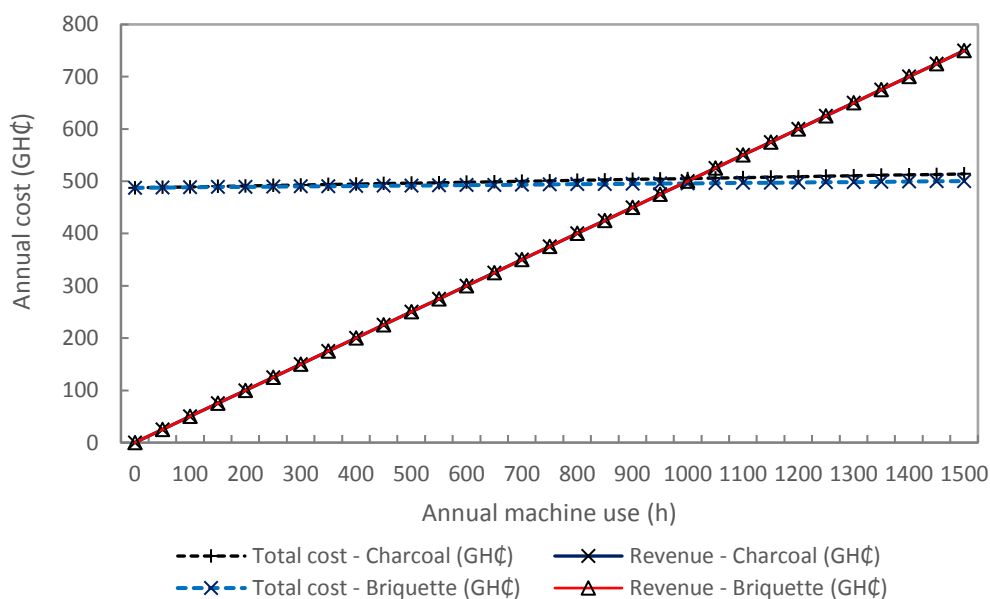


Figure 7: Breakeven chart for the rotatable grilling machine

CONCLUSION AND RECOMMENDATION

Charcoal and briquette fuel materials required 115 MJ and 73 MJ of energy per unit of fuel, respectively. Compared to charcoal, briquettes used substantially less energy. There were no appreciable changes in the results, however the energy efficiency of charcoal was 93.61% and that of briquettes was 92.92%. For charcoal and briquette, the specific fuel consumption was 1.06 and 0.90, respectively, although the results were not statistically different.

For charcoal and briquette, the effective grilling times were 0.53 h/kg and 0.37 h/kg, respectively. For charcoal and briquette, the effective grilling times were found to be 53 minutes and 37 minutes, respectively. Fish products may be safe for consumption since the cooking yield for grilled fish using charcoal was 72% and 70% for briquette.

The rotating fish grill has a break-even point with charcoal at 1010.9 hours and with briquettes at 991.83 hours. Briquettes appear to be a more cost-effective fuel option than charcoal for grilling fish.

Future studies should evaluate the organoleptic quality of fish grilled on a rotating grill to determine whether the finished product is acceptable to consumers. Nile Tilapia may be the subject of a similar investigation on the rotatable grill (*Oreochromis niloticus*).

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