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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(11): 1039-1045

www.thepharmajournal.com
Received: 15-08-2023
Accepted: 29-09-2023

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Development and evaluation of integrated cook stove and barbeque unit

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Abstract
The widespread use of traditional cook stoves burning unprocessed solid biomass fuels (SBFs) poses significant environmental and health risks due to incomplete combustion, leading to pollution and household air pollution (HAP)-related health issues. Developing countries, particularly rural areas in India, heavily rely on SBFs like fuel wood and crop residue for cooking. Barbeque is grilled slowly at temperatures ranging from about 79 to 149 °C and given smoke to add its flavour. A barbeque grill is a device that cooks food by applying heat from below. This study explores the potential of integrated cook stoves and barbeque unit to address these challenges by enhancing fuel efficiency, reducing health risks and prepare the various barbeque. It evaluates the performance of cookstove unit using various biomass feed stocks, such as mango and acacia sticks, assessing factors like flame temperature, thermal efficiency, and specific fuel consumption. The study also investigates the use of an integrated cookstove and barbeque unit, with sensory evaluations of barbeque products. The findings indicate the suitability of mango and acacia sticks as fuel for the developed cook stove, with favourable thermal efficiency. by using the mango sticks 26.24% and by using the acacia sticks it was found as 27.24% when tested for WBT. The average power output ratings of the cookstove unit for mango sticks and acacia sticks were 2.43 kW and 2.26 kW, respectively when tested for WBT. The integrated cookstove and barbeque unit show promise in terms of efficiency and barbeque product quality. Additionally, economic analysis suggests a favorable benefit-cost ratio for the unit's fabrication and operation.

Keywords: Proximate analysis, calorific value, integrated, cook stove, barbeque, benefit cost ratio

Introduction
There are currently 2.6 billion people without access to clean cooking facilities in this era of space travel, computers, and electronic devices (Kshirsagar and Kalamkar 2014) [2]. Around one-seventh of the world's energy demand is met by biomass resources, which also account for 40% of the total energy supply in developing nations (Jain and Sheth 2019) [3]. The World Health Organisation estimates that around three billion people (or 40% of the world's population) use open fire systems to heat and cook their homes, primarily utilising biomass or coal as fuel (Chica and Pérez 2019) [4]. In developing nations, there are substantial differences in the types of cooking fuel available in urban and rural locations, and these differences are mostly influenced by accessibility and income. While the rural community is strongly reliant on biomass, urban areas mostly rely on cleaner fuels like LPG (Liquefied Petroleum Gas), kerosene, or electricity. In India, up to 90% of the rural population lacks access to modern fuels, and up to 150 million tonne (MT) of biomass is consumed annually for cooking (Suresh *et al.*, 2016) [5].
According to estimates, India gets 47% of its energy from biomass sources. The growing population rate and lack of modern fuels can be attributed as the primary reasons for the rise in the utilization of biomass today. (Jain and Sheth 2019) [3]. Chulha is used to prepare food by 74% of the population. More than 80% of the total fuel utilised for domestic cooking in India is made up of solid biomass fuels such fuel wood, dung cake, and crop residue (Suresh *et al.*, 2016) [5].
Unprocessed solid biomass fuels (SBFs) combustion in conventional cook stoves has a major environmental impact. The usage of these types of fuels and cook stoves increases household air pollution, or HAP (Sidhu *et al.*, 2019) [6]. When biomass fuels are burned completely, carbon dioxide (CO_2) and water vapour (H_2O), which are less harmful, are the byproducts, whereas incomplete combustion releases pollutants and greenhouse gases (GHS), such as CO, N_2O, CH_4, and polycyclic aromatic hydrocarbons (PAHs), etc. that are harmful to human.

health. (Panwar N. L. 2009) [7]. Women and girls in rural communities spend many hours a week gathering fuel wood, which prevents them from attending school or working. According to the World Health Organisation (WHO), exposure to these emissions results in roughly 1.6 million premature deaths annually, more than half a million of which occur in India, as well as 4% of all greenhouse gas emissions and more than 30% of all BC emissions.

As a response to these global issues, energy and emission efficient improved cook stoves (ICSs) can reduce: infections by reducing indoor air pollution (IAP); the time and cost of getting fuel; the risk of violence against women and children gathering fuel in conflict areas; and the subsequent climate change and deforestation. There are currently more than 160 cook stove programmes active worldwide, in various countries (Kshirsagar and Kalamkar 2014) [2].

A physical structure known as a biomass cook stove uses air-fuel combustion to create heat and then directs that heat towards a cooking surface (a pot, pan or griddle). In addition to cooking, stoves offer useful energy for heating rooms and water, smoking food, and roasting grains and flour. In many cultures, the same object fulfils more than one of these purposes (Kshirsagar and Kalamkar 2014) [2].

While meat grilled over a charcoal or wood fire is common to many cultures around the world, Barbeque is cooked slowly at temperatures ranging from about 79 to 149 °C with more smoke than fire. Barbecue cooking is one of the most popular ways to prepare meat worldwide.

A barbeque grill is a device that cooks food by applying heat from below. Barbequing over charcoal grills is popular around the world. Every country have their own style of barbequing. It depends on the type of barbeque system. Charcoal grills require approximately 30 minutes or more to heat the charcoal to a temperature suitable for safe and effective cooking. barbeque products that increased in sales year over year. Charcoal grill still being used for barbequing purpose. Customers can pick from a variety of charcoal grills that come in all different sizes and shapes. Approximately 30 minutes or more is needed to heat the charcoal in a charcoal grill to a temperature appropriate for secure and efficient cooking.

In 2021, household applications had a sizable market share. Barbeque parties are increasingly popular worldwide, particularly in the United States, Canada, Mexico, the United Kingdom, Germany, China, and India. In addition to barbequed meat, a preference for other foods prepared on a grill has become more common at picnics, house parties, and gatherings of family and friends.

Materials and Methods

This chapter deals with the assumptions and methodology adopted for development and evaluation of integrated cook stove and barbeque unit. The step by step methodology to accomplish the research work is summarized under the following sub headings:

1. Biomass characterization
2. Development of integrated cook stove and barbeque unit
3. Performance evaluation of developed integrated cook stove and barbeque unit

Characterization of Biomass

Any biomass can be used as fuel, but the suitability and quality of the fuel must be determined through proximate analysis. It includes the estimation of fixed carbon, volatile matter, ash content, and moisture content. The sample of mango wood (*Mangifera Indica*) and acacia wood (*Acacia auriculiformis*) was collected and properly air dried before characterization. The proximate analysis and calorific value of collected samples is found by standard methods. The observations were recorded for three replications of each samples and average values were used. The results of the proximate analysis and calorific value are shown in Table 1.

Design of integrated cook stove and barbeque unit

The developed cook stove was designed for single family of five persons. The integrated cook stove and barbeque unit cook stove was fabricated by using the less expensive locally available materials. The developed unit offers efficient application.

Calculation for amount of energy required

Amount of heat required for cooking was calculated by following formula,

$$Qn = m \times Cp \times \Delta T \qquad (1)$$

Where,
Qn = Amount of heat require, kcal
m= Mass of material, kg
Cp = Specific Heat, kcal/kg and
ΔT= Temperature difference, °C
Qn =1254.26 Kcal
Assume Combustion efficiency, 30%
Consider, operational time required for cooking is 1.5
= 2787.24 Kcal/hr
= 11699.73 KJ/hr

Fuel consumption rate, FCR

Fuel consumption rate,

$$FCR = \frac{Qn}{HVf \times ή} \qquad (2)$$

Where,
FCR = Fuel Consumption Rate, kg/h
Qn = Heat energy needed, kJ/h
HVf = Calorific value of fuel, kJ/kg and
ή = Overall efficiency, (70% Assume)
FCR was calculated as,

FCR =1.06 kg/hr

Reactor volume, V

The volume of biomass reactor of biomass was calculated as

$$V = \frac{FCR}{\rho} \qquad (3)$$

Where,
FCR = Fuel Consumption Rate, kg and
ρ = Biomass density, kg/m3
$=1.43 \times 10^{-3}\ m^3$

Volume of combustion chamber

$$V = l \times w \times h \qquad (4)$$

(In rectangular combustion chamber h = w)

Where,
l = Length Of combustion chamber, m
w = Width Of combustion chamber, m
h = Height Of combustion chamber, m

Assume that Length of the combustion chamber = 15 cm = 0.15 m

w = 0.1095 m

From Above Results for 0.0019175 m^3 volume of combustion chamber the Length = 0.15 m was selected and also the width = height = 0.1095 m was selected.

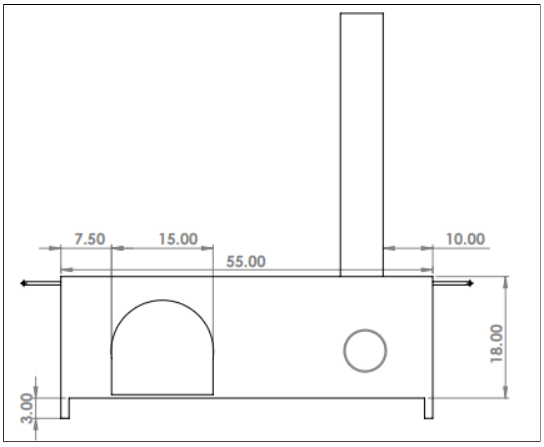
Design of chimney
The diameter of chimney was taken as 63.5 mm which is hollow pipe available in the market and height of chimney was taken as 1000 mm.

Wall thickness and insulation thickness
The M.S. Sheet of 16 Gauge was used for construction of the wall of the developed integrated cook stove and barbeque unit. Also the Ceramic Fiber sheet having one inch thickness was used for the insulation purpose on the all sides of the developed integrated cook stove and barbeque unit.

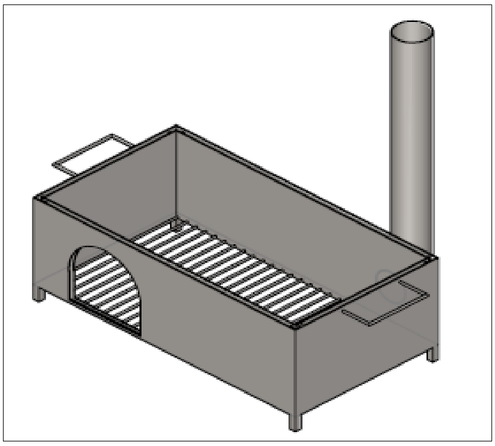
Flue duct
The flue duct was made in between the two pot openings. The flue duct was attached to the upper removable plate containing two pot openings. The length of the flue duct was 80 mm. There was no any slope is given to the flue duct (Vimal and Bhatt 1989) [8].

Grate
The grate was placed at the bottom of the combustion chamber for the both the purposes i.e. for cooking purposes and for the barbequing purposes. At the time of the cooking the wood is burn on the grate and the ash is removed from the combustion chamber and in the barbeque unit for giving the heat to roast the raw food pieces. The coal was placed on the grate and it was fired to create heat. The 6mm M.S. bars was used for the grate.

Barbeque unit
The integrated cook stove and barbeque unit was used for both the purposes i.e. for the cooking purposes and for the making barbeque purposes. For making barbeque the developed cook stove was converted into the barbeque unit by making two adjustments. First was to remove the chimney from the cook stove and the second was to remove the upper plate from the cook stove which consists of the two pot openings and the flue duct. Now the developed unit was known as barbeque unit. For making barbeque the skewers and the grate was required. The developed barbeque unit had the capacity of upto 6 skewers at a time. The 6 pieces of row food could be attached to each skewer.



Schematic front view of developed cook stove


Isometric View


Developed integrated cook stove and barbeque unit


Developed barbeque unit

Testing of developed cook stove

Efficiency was assessed using a water boiling test on various biomass, including mango and acacia sticks. The amount of water that evaporated was measured to determine the efficiency using the formula,

$$\text{Efficiency (\%)} = \frac{[(Mwi \times Cpw\ (Te - Ti) + mevap \times H1]_{p1} + [(Mwi \times Cpw\ (Te - Ti) + mevap \times H1]_{p2}}{(F \times CV)} \times 100 \quad \text{......(5)}$$

Where,

M_{wi} = Mass of water taken in cooking vessel, kg

C_{pw} = Specific heat of water, kcal/kg

m_{evap} = Mass of water evaporated, Kg

F = Mass of fuel burned, kg

T_e = Temperature of boiling water, K

T_i = Initial temperature of water in pot, K

H_i = Latent heat of vaporization of water at 373 K, 540 Kcal/Kg and

CV = Net calorific value of fuel, Kcal/Kg

The steps that were used to test the developed cook stove are listed below.

Power output rating

Calculations were made to determine the power output rating of the developed cook stove during the water boiling test.

$$\text{Power output rating (KW)} = \frac{(F \times CV \times \eta)}{(860 \times 100)} \quad (6)$$

Where,

F = Quantity of fuel burnt, Kg/h

CV = Calorific value of fuel, Kcal/Kg and

η = Thermal efficiency of the cooking stove, %

Cooking test

The actual cooking test of newly developed stove was carried out by conducting the cooking test for local food items i.e.1 kg rice. The cooking test was conducted to simulate traditional approach to rural areas of Konkan region. Stopwatch was set to monitor cooking duration and at the end of cooking mass of cooked food, the time taken for cooking as well as quantity of fuel remained were noted and recorded. Specific fuel consumption may be defined in terms of the quantity of fuel consumed per unit of food cooked.

Detail procedure of barbeque making

First, the paneer and chicken was cut into small pieces. Different spices were mixed it properly and left it 5 hours for marination. After that the small pieces were inserted into the skewers from the sharp end. When the coal was heated the skewers were placed on the barbeque unit in such a way that the both the ends of the skewers were supported by the walls so the food could be came above the coal and the handle of the skewers were outside of the barbeque unit. When the small pieces cooked properly which could required 15 to 20 minutes the pieces were removed from the skewers and served.

Sensory evaluation of developed barbeque products

The developed barbeque products made on developed barbeque unit were sensory evaluated by 25 panellists using a 9-point hedonic scale. On the provided score sheet, mean sensory scores for the quality attributes of appearance, colour, texture, aroma, taste and overall acceptability were recorded. The panellists were thus given samples of barbeque products made with chicken and paneer by applying three different spices on it.

Cost economics

The cost economics of developed integrated cook stove and barbeque unit was carried out. It included the evaluation of fixed cost, variable cost and raw material cost also the benefit/cost ratio calculated.

Results and Discussion

This chapter deals with findings of the study conducted to design and develop an integrated biomass cook stove and barbeque unit for a family.

Characteristics of Mango sticks and Acacia sticks

Proximate analysis

Mango (*Mangifera Indica*) and Acacia (*Acacia auriculiformis*) sticks were used for the study's biomass feedstock. According to ASTM D-3173, tests were conducted.

Table 1: Proximate composition of Mango sticks and Acacia sticks

Sr. No.	Biomass	Proximate composition, % (Average)			
		Moisture content (%) (w.b.)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)
1.	Mango sticks	8.4	57.4	3.167	30.96
2.	Acacia sticks	7.9	68.7	4.1	19.3

The results showed that the average moisture content was 8.4 percent and 7.9 percent, respectively and fixed carbon was found as 30.96 percent and 19.3 percent respectively for mango sticks and acacia sticks. For mango sticks and acacia sticks, the amounts of volatile matter and ash were found to be between 57.4 and 68.7 percent and 3.167 and 4.1 percent, respectively.

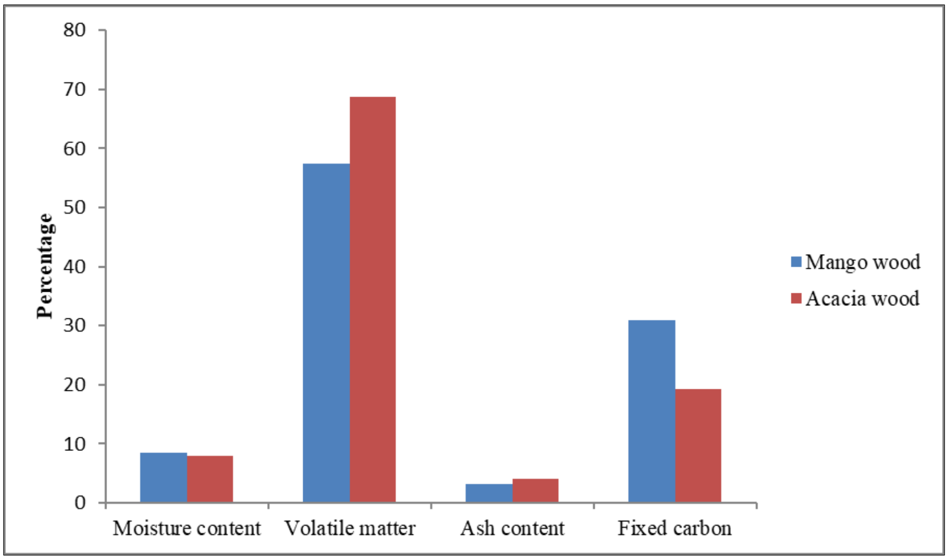


Fig 1: Proximate analysis of Mango sticks and Acacia sticks

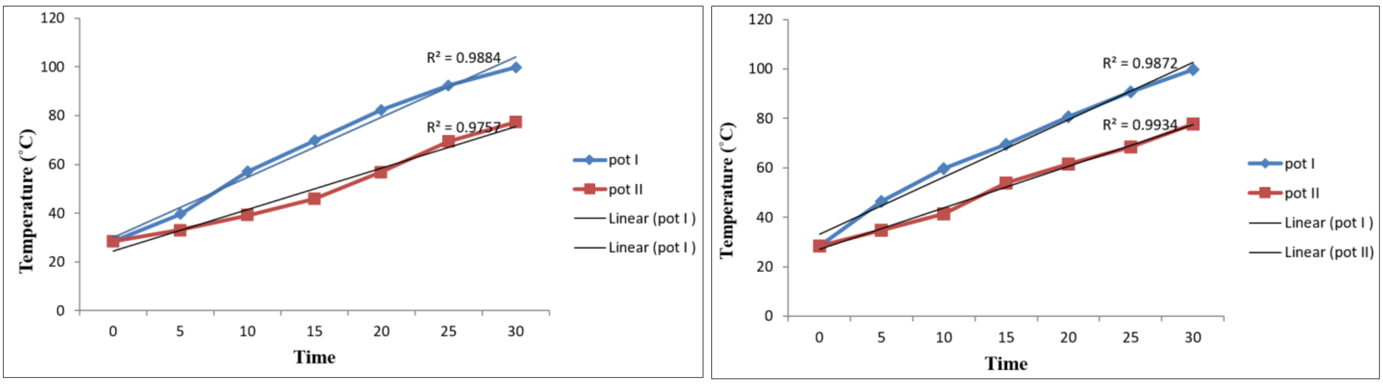
Higher calorific value of feed stocks
According to protocol, the Bomb Calorimeter (ASTME-711) was used to check the higher calorific value of the mango and acacia sticks, Mango sticks and acacia sticks had calorific values of 4168.6 kcal/kg and 3729.8 kcal/kg, respectively. Mango sticks' higher calorific value than Acacia sticks may be because of to the fact that their fixed carbon content was higher.

Table 2: Technical specifications of developed integrated biomass cook stove and barbeque unit

Sr. No.	Parameter	Dimensions
1.	Height of stove and barbeque unit walls, m	0.18
2.	Total Length of Cook Stove and barbeque unit, m	0.55
3.	Diameter of pot I. m	0.18
4.	Diameter of pot II. m	0.16
5.	Distance between two pots, m	0.08
6.	Height of chimney, m	0.90
7.	Diameter of chimney. m	0.063
8.	Height of legs. m	0.03
9.	Thickness of insulation. m	0.02

Flame temperature
The maximum flame temperature attained by developed cook stove for Mango sticks and Acacia sticks were 759 °C and 720 °C. The time taken for boiling water to boiling temperature for Mango sticks was less than Acacia sticks.

Water temperature
It was discovered that using Mango and Acacia sticks the time needed to reach boiling temperature was 26-27 and 27-28 minutes, respectively. When the temperature in the pot I was reached to the boiling point that time the temperature in the pot II using Mango and Acacia sticks was reached to the 76-78.5 ˚C and 77-78.2 ˚C respectively. The calorific value and flame temperature of the feedstock's were inversely related to the amount of time needed for water to boil.



a) Relationship between time and temperature while boiling of water by using Mango sticks

b) Relationship between time and temperature while boiling of water by using Acacia sticks

Fig 2: Water temperature of cook stove with respect to time

Stove surface temperature

The average temperatures attained by the stove outside surface during WBT were 57.08 °C and 51.46 °C for Mango sticks and Acacia sticks respectively. The stove surface temperature was found increased with increase in burning time.

Chimney temperature

During WBT of developed integrated cook stove and barbeque unit the by using the mango sticks and acacia sticks the average chimney temperature were obtained as 116.01˚C and 104.91˚C respectively.

Ash produced during WBT

The ash produced by various feed stocks was weighed resulting from the complete burning of the feed stock in a cook stove, the average ash produced after WBT for mango and acacia sticks was found to be 24 g and 19.33 g respectively. Total ash produced depends upon type of biomass used.

Thermal Efficiency

The thermal efficiency of the developed cook stove was calculated by using the mango sticks and acacia sticks. The average thermal efficiency was 26.24% with mango sticks and 27.24% with acacia sticks. The thermal efficiencies which were found in the developed cook stove were more than the thermal efficiencies of the traditional mud stove (17.9%) and improved vented cook stove (10 – 23%) (Ayo, 2009) [1].

Power output rating

After WBT, the average power output ratings for mango sticks and acacia sticks were 2.43 kW and 2.26 kW, respectively.

Cooking test

The actual cooking test was carried out by cooking rice with selected feed stocks. The time spent in cooking rice per kg of cooked food was found to be 0.16 hr/kg and 0.17 hr/kg for Mango sticks and Acacia sticks respectively and the specific fuel consumption (SFC) was calculated 0.25 and 0.27 kg/kg for Mango sticks and Acacia sticks respectively. The developed cooking stove was found safe during operation and no difficulties were found at the time of cooking.

Sensory Evaluation of different barbeque items

Some of the commercially available products were prepared using the developed barbeque unit, i.e. chicken tikka, chicken malai tikka, chicken pahadi tikka (green chicken), paneer and paneer tikka. The sensory evaluation of the products was carried out for various quality attributes like appearance, colour, texture, aroma, taste and overall acceptability. The barbeque items C1, P2 and C3 i.e. which were made up of the red tikka masala and pahadi tikka masala (green masala) respectively and they were liked more by the pannelists and gave overall acceptability as 8.32, 8.04 and 8.08 respectively. It was found from the sensory evaluation, that the developed barbeque unit was able to prepare the different barbeque items similar to commercially available products.

Table 3: Average Sensory Score Values of different barbeque items

Treatments	Appearance	Colour	Texture	Aroma	Taste	Overall acceptability
C1	8.36	8.12	8.00	7.72	8.12	8.32
C2	7.44	7.48	7.72	7.60	7.76	7.76
C3	7.84	8.04	7.80	7.80	8.00	8.08
P1	7.36	7.56	7.56	7.52	7.72	7.68
P2	8.24	8.32	7.83	7.84	7.92	8.04

From the above table, it was found that the barbeque items were prepared on the developed barbeque unit had the good score ratings. The results got from the sensory evaluation it was clear that the developed barbeque unit was able to make the different barbeque items which were easily available in the local market and developed barbeque unit was helpful for restaurants, roadsides small barbeque stalls and also for preparing the barbeques at home.

Cost economics

Total cost of fabrication of integrated cookstove and barbeque unit was Rs. 4,724/-Total fixed cost of the unit was Rs1,218 /-, the total variable cost was Rs2,40,000/- and the raw material cost was Rs13,86,000/-. The total capital investment i.e, production cost per year was Rs16,27,218/-. By considering the selling price Rs130 per skewer, the net profit per year was Rs 7,12,782/-. The Benefit/cost ratio was found to be 1.43.

Conclusions

The average thermal efficiency of the cookstove unit was found by using the mango sticks 26.24% and by using the acacia sticks it was found as 27.24% and the average power output ratings for mango sticks and acacia sticks were 2.43 kW and 2.26 kW, respectively when tested for WBT. The specific fuel consumption (SFC) of the cookstove unit was found to be 0.25 and 0.27 kg/kg for Mango sticks and Acacia sticks, respectively. The time required to cook rice per kg of cooked food was 0.16 hr/kg and 0.17 hr/kg for Mango sticks and Acacia sticks, respectively.

The developed integrated cookstove and barbeque unit was able to prepare the various barbeque products as of same quality commercially available in market. Positive feedback were received from the commercial operators regarding to the working of developed unit and ease of operation. The total capital investment for barbeque making i.e., production cost per year was Rs16,27,218/-. By considering the selling price Rs130 per skewer the net profit per year was Rs 7,12,782/-. The Benefit/cost ratio was found to be 1.43.

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