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Performance evaluation and testing of low cost portable-Type improved cook stoves

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Abstract
Present investigation was carried out on performance evaluation of four different types of low cost improved cook stoves at four different biomass fuels. Boiling time, burning rate, thermal efficiency, power output rate and fuel consumption were the main performance indicators that were assessed using water boiling test (WBT). The experimental results were analysed statistically using Statistical Analysis System (SAS). The mean values obtained from each set were compared using tukey multiple comparison test based on a complete randomized design (at 0.05 confidence level). Results revealed that cook stoves and fuels significantly affected the performance indicators and their combined impact is also meaningful ($p \leq 0.05$). It was observed that fuel consumption of SPRERI side feeding cook stove was maximum (1882±8.5 kg), burning rate (3.61±0.14 kgh^{-1}) for fuel wood chips, minimum boiling time (12±0.24 minute) with fuel wood, thermal efficiency (24±0.88%) with dung cake. Greenway Smart model takes the maximum boiling time (48±1.25 minute) with fuel wood chips, it shows good thermal efficiency (26±0.26%) with cattle dung cakes and having low burning rate (0.86±0.02 kgh^{-1}) with wood chips. Greenway Jumbo model had lower fuel consumption (634±13.49 kg), highest thermal efficiency (26±0.55%) among all the cook stoves and had lower burning rate (0.95±0.01 kgh^{-1}) with wood chips. From the statistical assessment, SPRERI side feeding cook stoves found to be efficient as mean boiling time was less and had higher mean power output rate followed by Greenway Smart model with highest mean thermal efficiency and lower fuel consumption.

Keywords: improved cook stoves, water boiling test, statistical analysis system, biomass, Tukey, thermal efficiency

1. Introduction

Energy is the primary requirement for socio-economic development of any society. In most of the developing countries, biomass and solid fuels are the primary source of energy for the majority of people living in rural areas. Worldwide, approximately three billion people use solid fuels that are biomass (wood, wood chips, animal excreta and crop residue) and coal to accomplish household energy needs. In cooking of food about half of the world's population uses biomass fuels (Bruce *et.al.* 2000) [4]. Cooking with biomass generates very high amount of air pollution which is the main reason to 2.6% of global illness (Rumchev *et al*., 2007) [8]. Solid fuels are regularly burnt in presence of inadequate ventilated indoor or near house-hold outdoor conditions utilising inefficient conventional cook stoves. Traditional cook stoves increase indoor concentrations of certain pollutants, such as particulate matter, carbon monoxide, NO_2, SO_2, benzene and formaldehyde which are released from the fuel wood and other fuels burnt at the time of cooking. Such exposures are linked to acute respiratory infections, chronic obstructive lung diseases, low birth weights, lung cancer and eye problems (Kaoma and Kasali, 1994) [7]. Duflo *et al* (2008) [6] surveyed rural Orissa, India and reported that one-third of the adults and half of the children had experienced symptoms of respiratory illness in the 30 days preceding the survey, with 10 per cent of adults and 20 per cent of children experiencing a serious cough due to the regular use of traditional cook stoves.

In India, 60% of total population lives in rural areas. But, unfortunately majority of rural people, follow an unhygienic life style. About 60% of people use traditional biomass for their daily cooking requirements, among them, wood constitutes 62.5%, crop residue constitutes 12.3% and cattle dung constitutes 10.9% (Anon, 2012) [1].

Due to excess utilisation of wood and biomass fuels, a rapid depletion in natural forest resource was noticed. To overcome these problems related to deforestation and women health hazard, Government of India initiated the National Programme on Improved Chulha (NPIC) in 1984-85. The fundamental goal of the program was to lessen the interest for fuel-wood, expanding the fuel-utilize effectiveness of wood-burning stoves, diminish the drudgery related with cooking, particularly of ladies, risks caused by smoke, heat exposure in the kitchen and save and advance the utilization of fuel wood, particularly in the rural and semi-urban regions and to realize enhancement in household sanitation and general living conditions.

In any case, persistent innovation or improvement will tame biomass disservices and enable biomass to be utilized with considerably more noteworthy effectiveness and incredibly diminished ecological effect. Keeping in view the problems related to traditional chullas, the present investigation on performance evaluation of four different kinds of improved cook stoves was carried out. This paper also reports thermal efficiency and power output rate of each improved cookstove.

2. Material and Methods

Present study was conducted at Department of Processing and Food Engineering, CCS Haryana Agricultural University, Hisar, Haryana (India). During the study, four available models of improved biomass cook stoves were taken; two models of Greenway make (Jumbo and Smart) and two models of SPRERI make (Side Feeding and Top Feeding). Four fuels used to test the performance of these cook stoves were coal, cattle dung cake, wood and wood chips as shown in Fig.1. The performance indicators studied during the experiments were boiling time, burning rate, fuel consumption, thermal efficiency and power output rate.

Comparison of data was carried out with the help of Statistical Analysis System (SAS) at 5% level of significance. The mean values obtained from each set were compared using tukey multiple comparison test based on a complete randomized design (at 0.05 confi dence level). Combined effects of fuel and cook stoves on boiling time, burning rate, fuel consumption, thermal efficiency and power output rate were analysed and results were presented in the form of ANOVA table and graphs. Probability values in the final column must be less than 5% for accepting the effectiveness assumption.

Fig 1: Fuels used for experimental study

2.1 Description of improved cook stoves

The improved cook stoves were single burner with high efficiency as compared to traditional chullas. These cook stoves were portable type which comprised of combustion chamber with primary and secondary holes, grate for ash separation, stand and handle as shown in fig. 2. Cook stoves were made up of GI sheet having two cylinders, inner one was used as combustion chamber and outer one was used for safety purposes and reduced the heat transfer losses. The dimensions of improved cook stoves are presented in Table 1. Each cookstove was tested in triplicate with each available biomass i.e. wood, coal, cattle dung and wood chips, respectively.

Fig 2: Four type of improved cook stoves used in experimental study

Table 1: Dimensions of Improved Cook stoves

Dimensions (cms)	Greenway		SPRERI	
	Smart	Jumbo	Side Feeding	Top Feeding
Outer diameter	19.5	27.0	28.5	25.5
Inner diameter	11.5	11.5	19.0	17.0
Height	28.0	28.5	31.5	29.5
Feeding hole	13.5 x 13	14 x 14	9 x 8	NA
Stove- pot clearance	2.0	2.0	4.0	3.5
Ground clearance	3.5	3.5	2.5	4.5
Circumference	61.0	85.5	86.5	79.5
Weight (gm)	5650	4390	2790	3470
Cost (Rs.)	1240	2170	1300	1250

2.1.1 Greenway Smart

It was a portable-type, cylindrical in shape with inner diameter and height of 11.5 and 28 cm. The total weight of stove was 5.650 kg which made it easier to transport from one place to another due to its light weight. It was suitable for a medium sized family (6-8 members). It was found to be very popular in many states of India, especially in villages of Haryana and Punjab. A variety of fuels such as wood, cattle dung cake, wood chips, coal and other similar agri-residue could be used. The stove has spherical bottom of 19.5 cm in diameter. The cost of the cookstove was about Rs.1240 per piece. Due to the double wall design feature, complete combustion took place. The stove, therefore, can attain very high thermal efficiency, comparatively higher power output, faster cooking and lower emissions.

2.1.2 Greenway Jumbo

The Greenway Jumbo was more popular, portable, metallic and non-chimney cook stove. The cook stove had a diameter and height of 11.5 and 28.5 cm, respectively. The total weight of the stove was 4.390 kg and very suitable for large sized family (8-10 members) or small Dhabas. The stove is specifically suitable for fuel wood. The cost of this cook stove, depending on its size and material specifications was Rs. 2170 per unit. Due to the double wall design feature, coupled with grate (for provision of hot secondary air from underneath), complete combustion took place. The stove therefore can attain very high thermal efficiency, but comparatively lower than Smart cook stove.

2.1.3 SPRERI (Side Feeding)

The SPRERI (Side Feeding) was a portable, metallic, single-pot stove without chimney, designed as an alternative to traditional chullas that was specifically suitable for fuel wood and cattle dung cakes. Besides fuel wood, the SPRERI cook stove (Side Feeding) could be used with coal and a variety of agro-residues or with different fuel combinations. It could be used with vessels of diameter in the range of 19-30 cm. The model, with a corrugated grate design with scraper (for periodical ash removal), can be manufactured by small shops having facilities for welding, cutting, grinding and punching sheet metal up to a thickness of 3mm. The cost of the cookstove was Rs. 1300 per unit.

2.1.4 SPRERI (Top Feeding)

The SPRERI (Top Feeding) was a low cost, single-pot, portable type stove without chimney. The design was meant for general use, but had taken into account the cooking needs of weaker sections of the society. The stove can accommodate flat or spherical pots with inner and outer diameter of 17 and 26 cm, respectively and could be used with fuel wood, twigs, cattle dung cakes, agro-residues and briquettes. It was suitable for a medium-to-large family of 6-10 members. It could be operated either as a fixed stove or as a portable one. Due to the double wall design feature, coupled with the fired-clay grate, complete combustion took place. The stove, therefore could attain good thermal efficiency, comparatively lower than Jumbo and Smart one. The cost of the cook stove was Rs. 1250 per unit.

2.2 Description of Fuel used

Coal, cattle dung cake, wood and wood chips were the four biomass fuels used during experiments shown in figure 1. They are locally available biomass fuel used by the rural people for their cooking and energy purpose. The net calorific value of the fuels used in calculation is presented in Table 2.

Table 2: Description of Fuel used

S. No	Biomass Fuel used	Calorific Value (kJ/kg)	Moisture content (% wb)
1	Wood	19500	8.0
2	Coal	29000	2.0
3	Cattle dung cakes	7000	10.0
4	Wood chips	10500	14.0

2.3 Determination of moisture content

The moisture content of the fuel sample was determined by pre-weighing a sample of the biomass fuel and placing in an open-air oven at 105 °C for 2 hours. The sample was then allowed to cool to room temperature in desiccator and re-weighed. The moisture content was calculated as a ratio of the weight loss due to moisture drying and the weight of the biomass fuel with moisture as depicted in Equation 1

$$\text{Moisture content } (\%wb) = \frac{\text{wt. of fuel with moisture } (g) - \text{wt. of dried fuel } (g)}{\text{wt. of fuel with moisture } (g)} \quad 1$$

2.4 Water boiling test

Water Boiling Test (WBT) is short, simple simulation of standard cooking procedure. It measures the fuel consumed and time required for observed cooking. The test is usually employed to investigate the performance of cookstove under different operating conditions used by stove designers, researchers and field workers. The data obtained were used to compute the thermal efficiency for each stove using equation 2 (Danshehu *et al.* 1992) [5].

$$Thermal\ efficiency\ (\%) = \frac{HU}{HP} \times 100 \quad 2$$

$$HU(Q) = m_w \times c \times \Delta t$$

$$HP(Q) = m_f \times B$$

Where

HU= Heat utilised
HP= Heat produced
m_w = Mass of water (kg)
c = Specific heat of water (kJ/kg°C)
Δt = Change in temperature (°C)
m_f= Amount of fuel used (kg)
B= Calorific value of fuel (kJ/kg)

2.5 Burning Rate

Burning rate tests were investigated on each improved cookstove. Appropriate amount of fuel was charged into each cookstove. The initial and final weight of the fuel at start and at the end of test, were recorded. This test was repeated thrice for each cookstove and the average burning rate value was calculated using equation 3 (Bolaji and Olalusi, 2009) [3].

$$R = \frac{100(W_i - W_f)}{(100+M)t} \quad 3$$

Where

R = Burning Rate, kg/hr
W_i = Initial weight of fuel at start of test, kg
W_f =Final weight of fuel at end of test, kg
M = Moisture content of fuel, %
t = Total time taken for burning fuel, hr.

2.6 Power output rate

The power output rating of improved cook stoves is a measure of total useful energy produced during one hour burning of fuel wood. The data of thermal efficiency and calorific value of fuel wood obtained were used to compute the power output rate for each stove using equation 4 (Venkataraman *et al.*,1987) [9].

$$P = \frac{F_c \times C_v \times T_e}{860 \times 100} \quad 4$$

Where
P = Power Output Rating, kW
F_c = Quantity of fuel wood burnt, kg/h
C_v = Calorific value of fuel wood, kCal/kg
T_e = Calculated thermal efficiency of the cook stoves

3. Results and Discussion

Performance study of improved cook stoves at different fuels was carried out and presented in given below tables 3, 4, 5 and 6, respectively. The results were statistically analyzed and presented in the form of graphs and ANOVA tables.

Table 3: Performance of cook stoves using fuel wood

Performance indicators	Greenway		SPRERI	
	Smart	Jumbo	Side feeding	Top feeding
Fuel Consumption, g	338±6.24	395±17	518±19.20	600±20.55
Boiling Time, min.	18±0.47	14±1.55	12±0.24	15±0.62
Burning Rate, kg/hr	1.06±0.01	1.56±0.17	2.41±0.07	2.22±0.15
Thermal Efficiency,%	21.08±0.75	19.83±4.13	14.63±0.61	12.89±0.89
Power output rate, kw	1.21±0.01	1.64±0.5	1.90	1.54±0.10

Table 4: Performance of cook stoves using fuel coal

Performance indicators	Greenway		SPRERI	
	Smart	Jumbo	Side feeding	Top feeding
Fuel Consumption, g	908±11.59	917±4.78	1114±11.03	1134±4.92
Boiling Time, min.	28±0.47	26±1.25	22±0.82	36±1.7
Burning Rate, kg/hr	1.93±0.06	2.11±0.11	2.98±0.10	1.84±0.10
Thermal Efficiency,%	6±0.11	6±0.06	5±0.08	4±0.07
Power output rate, kw	0.94	1.00±0.01	1.15	0.59

Table 5: Performance of cook stoves using fuel cattle dung

Performance indicators	Greenway		SPRERI	
	Smart	Jumbo	Side feeding	Top feeding
Fuel Consumption, g	939±9.42	955±4.08	975±10.80	1752±30.64
Boiling Time, min.	44±1.25	43±1.25	29±1.63	42±2.05
Burning Rate, kg/hr	1.16±0.03	1.19±0.04	1.82±0.09	2.28±0.14
Thermal Efficiency,%	26±0.26	22±0.99	24±0.88	14±0.46
Power output rate, kw	0.56	0.50	0.85±0.01	0.60

Table 6: Performance of cook stoves using fuel wood-chips

Performance indicators	Greenway		SPRERI	
	Smart	Jumbo	Side feeding	Top feeding
Fuel Consumption, g	781±8.29	634±13.49	1882±8.5	1848±8.5
Boiling Time, min.	48±1.25	35±0.94	28±0.94	25±1.08
Burning Rate, kg/hr	0.86±0.02	0.95±0.01	3.61±0.14	4.01±0.19
Thermal Efficiency,%	21±0.22	26±0.55	8±0.04	8±0.04
Power output rate, kw	0.52±0.01	0.71	0.88	0.99

3.1 Fuel Consumption

Table 7 shows ANOVA results for effect of different kind of biomass fuel and cook stoves on fuel consumption. Results shows that biomass fuel and cook stoves, individually have a meaningful impact on fuel consumption and their combined effect is also found significant ($p<0.05$). The Model F-value of 2497.39 suggests the model is highly significant. The model developed between biomass fuel and cook stoves and their combined effect was found significantly (R^2 = 0.9992, RMSE= 16.70) predictable at 5% level of significance with coefficient of variation of only 1.70%.

Table 7: Effect of biomass fuel and improved cook stoves on fuel consumption

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	10457027.15	697135.14	2497.39	<.0001
Fuel	3	4680450.72	1560150.24	5589.01	<.0001
Cookstove	3	3300688.72	1100229.57	3941.42	<.0001
Fuel*Cookstove	9	2475887.68	275098.63	985.50	<.0001
Error	32	8932.67	279.15		
Corrected Total	47				

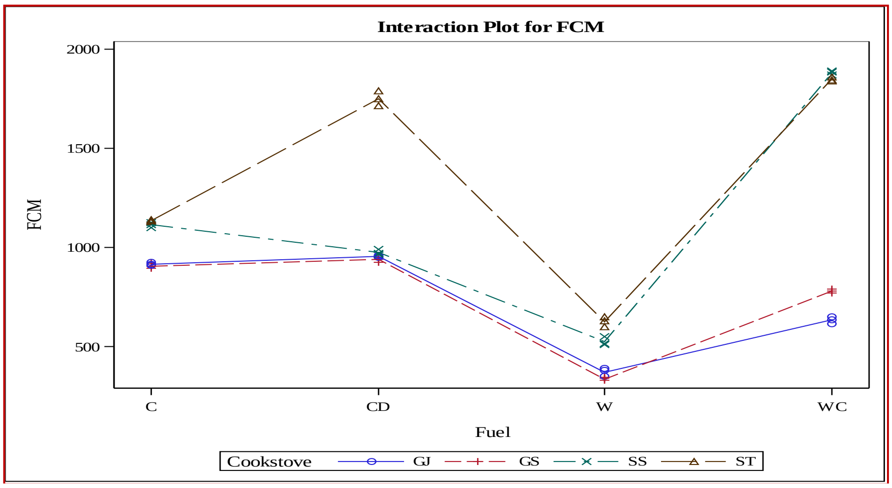

Fig 3: Amount of fuel consumed by cook stoves

Figure 3 shows the total fuel consumed by each cookstove during accomplishing the cooking operation. The results revealed that the fuel consumed was statistically lower for wood (338±6.24 kg) in case of Greenway smart and higher for wood chips (1848±8.5 kg) in case of SPRERI Top feeding. It was observed that mean fuel consumption for model SPRERI top feeding remains higher and lower for Greenway smart for each fuel. In case of SPRERI side feeding, the statistical analysis from results shows that the fuel consumed was maximum and minimum for wood chips (1882±8.5 kg) and cow dung cake (975±10.80 kg). Likewise in case of Greenway Jumbo and Greenway Smart, the fuel (coal, cow dung cake and wood) consumed was relatively equal but woodchips was consumed relatively higher in Greenway smart (781±8.29 kg) as compare to greenway jumbo (634±13.49 kg).

3.2 Boiling time

Boiling time for water is a necessary parameter that was studied under investigation carried out. The results are very clear from the figure 4; it was found statistically that the fuel wood having better performance with each cookstove due to less boiling time. The water starts boils and takes less time that was ranges in between 12±0.24 to 18±0.47 minute in case of fuel wood. Fuel wood used with SPRERI (side feeding) taken approximately 12±0.24 minute time to boil water and similarly greenway (smart) taken approximately 18±0.47 minute for boiling water. SPRERI (side feeding) shows better boiling time with each fuel used except wood chips. The water boiling time was higher for cow dung cake (44±1.25 minute) and wood chips (48±1.25 minute) in case of Greenway (smart) followed by Greenway (Jumbo), 35±0.94 and 43±1.25 minute for wood chips and cow dung cake.

Results revealed that kind of fuel and type of cookstove have significant effect on boiling time. It was found that the improved cook stoves (ST, GJ and GS) are inefficient to burn cow dung cake and wood chips due to which burning time increase which leads to increase in boiling time of water. Table 8 presents the statistical results of boiling time that was affected by different type of fuel and cook stoves. Results demonstrates that biomass fuel and cook stoves, independently meaningfully affect boiling time and their combined impact is likewise found significant ($p<0.05$). The Model F-value of 185.14 recommends the model is highly significant. The model created between biomass fuel, cook stoves and their combined impact was found significantly ($R^2 = 0.9886$, RMSE= 1.46) foreseeable at 5% level of significance with coefficient of variation of just 5.05% and further supports the reliability of the model.

Table 8: Effect of biomass fuel and improved cook stoves on boiling time

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	5959	397	185.14	<.0001
Fuel	3	4120	1373	639.94	<.0001
Cookstove	3	834	278	129.52	<.0001
Fuel*Cookstove	9	1006	112	52.08	<.0001
Error	32	32	69	2.14	
Corrected Total	47	47	6028		

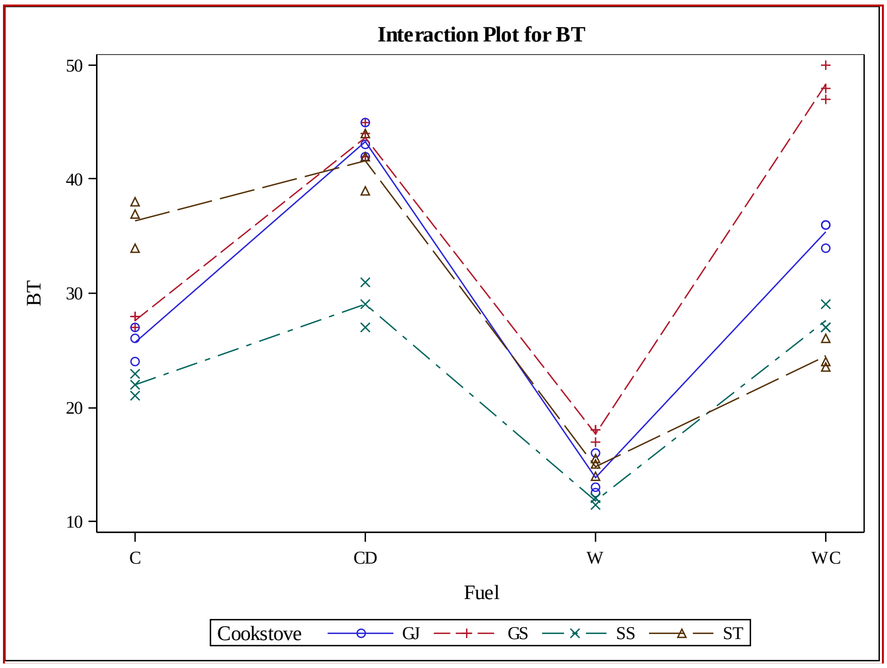

Fig 4: Water boiling time taken by each cook stoves

3.3 Thermal efficiency

Thermal efficiency is the ratio of heat utilized in evaporating water to the heat produced by the fuel. The thermal efficiencies of the improved cook stoves were determined for each fuel at 5% level of significance. It was found statistically, that each cookstove has varying thermal efficiency according to the fuel used. It was observed that cook stoves with fuel coal has lowest efficiency (< 10%) as compared to other fuels. The Greenway smart (26±0.26%) with fuel cow dung cake and Greenway jumbo (26±0.55%) with fuel woodchips attains the maximum efficiency. It was proven statistically that each cook stove depends on kind of fuel and its quality. Figure 5 shows that model SPRERI (top feeding) was inefficient to attain thermal efficiency higher than other cook stoves at each fuel. The maximum efficiency gained by this model was 14±0.46% with fuel cow dung cake. Result shows that Greenway (jumbo and smart) models are efficient in gaining higher thermal efficiency and suitable for biomass used.

The results for thermal efficiency were statistically analyzed at 5% level of significance and it was observed from the table 9 that model is highly significant ($p< 0.05$) with F-value of 95.01. Fuel and Cook stoves, individually have significant effect on thermal efficiency and their combined effect is also found significant. Further the reliability of the model is supported by R^2 and *CV*% value for thermal efficiency was 0.9780 and 9.45% respectively with RMSE = 1.41 which indicated that the model could fit the data for thermal efficiency very well for fuel and cook stoves both.

The results from the determination of thermal efficiencies of improved cook stoves indicated that Greenway smart was the most efficient among the four in case of fuel cow dung cake and jumbo was most efficient among the four in case of fuel wood chips.

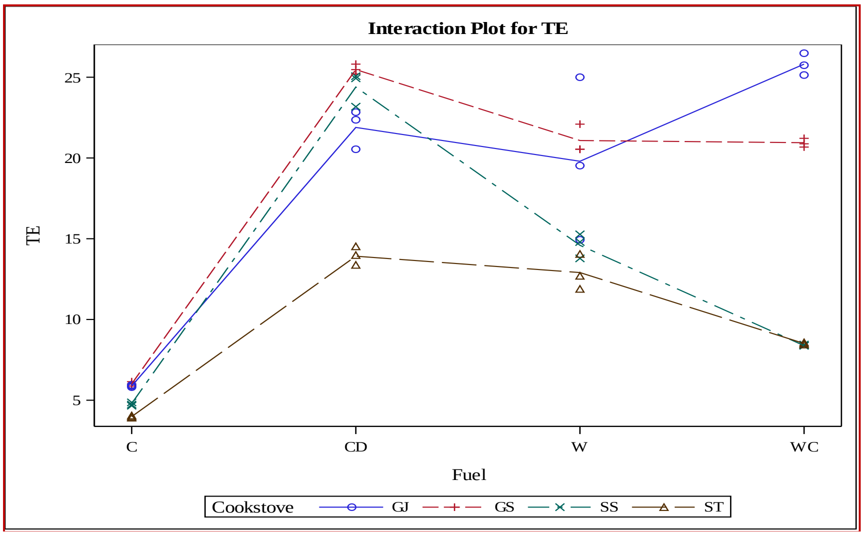

Fig 5: Thermal efficiency of improved cook stoves at different fuels

Table 9: Effect of biomass fuel on thermal efficiency of improved cook stoves.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	28230	189	95.01	<.0001
Fuel	3	1729	576	290.17	<.0001
Cookstove	3	639	213	107.34	<.0001
Fuel*Cookstove	9	462	51	25.85	<.0001
Error	32	64	2		
Corrected Total	47	2893			

3.4 Burning rate

Tests on burning rate were carried out with each improved cook stoves at four different fuels presented in figure 6. The way toward consuming fuel in a combustion chamber of a cookstove decides the subsequent system performance. Number of factors can affect the burning rate of solid fuels. Some of the factors are air and fuel mixture ratio, combustion chamber and size of fuel. The results of burning rate were analyzed statistically to find the effect of fuels and cook stoves used in the study. The burning rate of the fuels used in greenway smart and jumbo were approximately similar at 1.93±0.06, 1.16±0.03, 1.06±0.01, 0.86±0.02 kgh^{-1} and 2.11±0.11, 1.19±0.04, 1.56±0.17, 0.95±0.01 kgh^{-1} respectively for coal, cow dung cake, wood and woodchips. The burning rate of fuel wood chips in case of Greenway smart (0.86±0.02 kgh^{-1}) and jumbo (0.95±0.01 kgh^{-1}) was found to be lower but the results are statistically significant and there will be a significant effect on burning rate due to cook stoves and the fuels used for tests.

The burning rate of the fuels used in SPRERI (top feeding) and SPRERI (side feeding) were found to be higher at 1.84±0.1, 2.28±0.14, 2.22±0.15, 4.01±0.19 kgh^{-1} and 2.98±0.1, 1.82±0.09, 2.41±0.07, 3.61±0.14 kgh^{-1} respectively for coal, cow dung cake, wood and woodchips. It was found that both model of SPRERI have statistically higher burning rate as compared to both model of Greenway. This could be due to the fact that there are other design parameters that far more than compensate for the effect of surface area to volume ratio and wall cooling in the determination of the burning rate in the cook stoves (Boafo-Mensah *et al*, 2013) [2]. The effect of the particle size of the fuel and the homogeneity of the fuel on the burning rate is expected to be significant since similar size fuel was not used for each cookstove test. Both the models SPRERI top feeding (4.01±0.19 kgh^{-1}) and SPRERI side feeding (3.61±0.14 kgh^{-1}) attains the higher values of burning rate that was found statistically significant. It was also observed from the results that fuel cow dung cake shows lower burning rate with each cook stoves, Greenway smart (1.16±0.03 kgh^{-1}),Greenway jumbo (1.19±0.04 kgh^{-1}), SPRERI top feeding (1.82±0.09 kgh^{-1}), SPRERI side feeding (2.28±0.14kgh^{-1}), respectively. Results of analysis of variance were presented in table 10 shows that fuel and cook stoves individually have statistically significant ($p<0.05$) effect on burning rate and their combined effect is also found highly significant at 5% level of significance. R^2 and *CV*% value for burning rate was 0.9854 and 6.65% respectively with RMSE = 0.132 which indicated that the model could fit the data for burning rate very well for fuel and cook stoves both. The Model F-value of 144.08 implies the model is significant.

Table 10: Effect of biomass fuel on burning rate of improved cook stoves.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	38.19	2.54	144.08	<.0001
Fuel	3	4.29	1.43	80.91	<.0001
Cookstove	3	20.35	6.78	383.88	<.0001
Fuel*Cookstove	9	13.55	1.50	85.20	<.0001
Error	32	0.56	0.02		
Corrected Total	47	38.76			

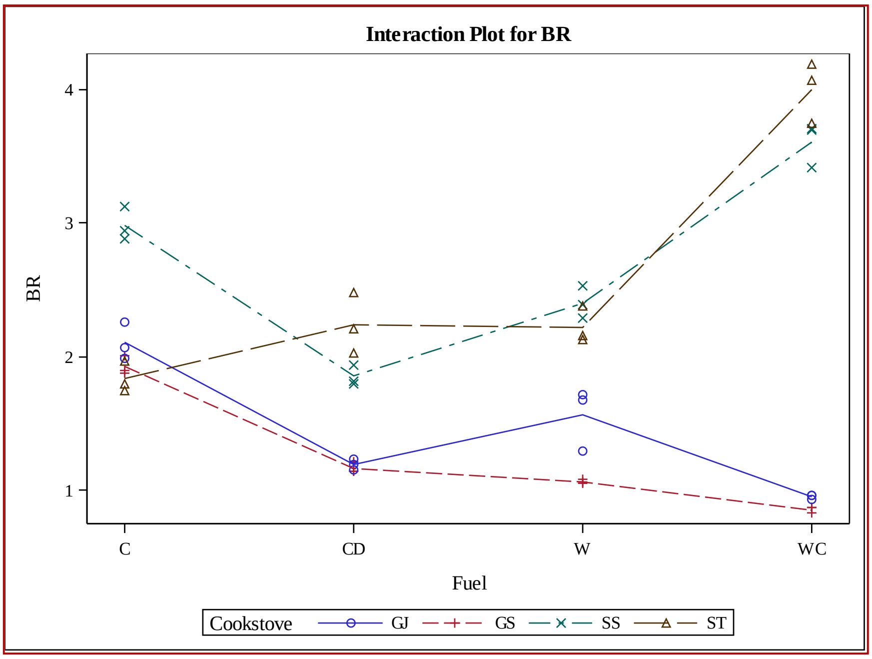

Fig 6: Burning rate of improved cook stoves at different fuels

3.5 Power output rate

The mean power output rate (1.15, 0.86±0.01 and 1.90 kW) of SPRERI side feeding was found statistically higher than other cook stoves for coal, cow dung and wood respectively. The highest power output was determined to be 1.90 kW for SPRERI side feeding, 1.64±0.5 kW for Greenway Jumbo, 1.54±0.10 kW for SPRERI top feeding and 1.21±0.01 kW Greenway Smart with fuel Wood. It was also found that power output rate of each cook stove is lower than 1 kW with fuel coal, cow dung and woodchips. Figure 7 shows that the lower power output rate was determined to be 0.52±0.01 kW for Greenway smart with wood chips, 0.59 kW for SPRERI top feeding and 0.50 for Greenway jumbo with cow dung cake. Table 11 shows Analysis of Variance results for fuel, cook stoves and their combined effect on power output rate. ANOVA results shows that model is highly significant (p<0.01) with F-value of 95.79. Fuel and cook stoves individually have statistically significant (p<0.05) effect on power output rate and their combined effect is also found highly significant at 5% level of significance. R^2 and *CV*% value for power output rate was 0.9782 and 7.69% respectively with RMSE = 0.07 which indicated that the model could fit the data for power output rate very well for fuel and cook stoves both.

Table 11: Effect of biomass fuel on power output rate of improved cook stoves.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	8.06	0.537	95.79	<.0001
Fuel	3	6.23	2.079	370.45	<.0001
Cookstove	3	0.95	0.318	56.69	<.0001
Fuel*Cookstove	9	0.87	0.096	17.28	<.0001
Error	32	0.17	0.005		
Corrected Total	47	8.24			

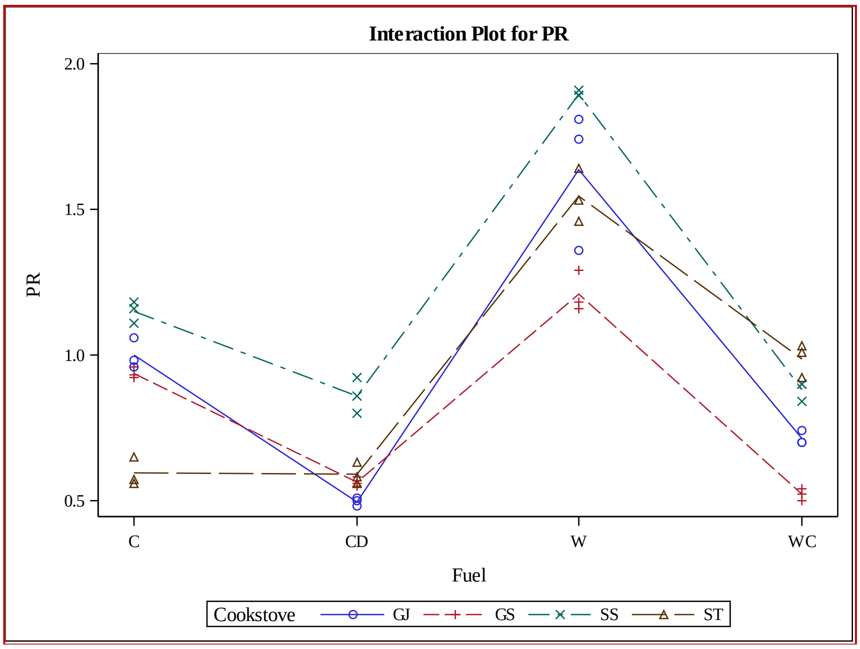

Fig 7: Power output rate of improved cook stoves at different fuels.

4. Conclusion
The performance of improved cook stoves was found to be satisfactory and statistically analysed. These are portable type, easy to use and give very less smoke. However the smoke emission was different for different fuels. Improved cook stoves are suitable for wood, cow dung and wood chips but in case of coal, they consume much fuel and efficiency is also low. Thermal efficiency of GREENWAY cook-stoves is better than SPRERI cook-stoves. Greenway (jumbo) model has highest thermal efficiency with woodchips (26±0.55%) but it required a sieve of small openings over the grate. All the cook-stoves consumed least time for boiling of water with wood and thermal efficiency was also high with wood. In case of coal, a forced circulation of air is required for proper burning of coal. Improved cook stoves consume less fuel and produce less smoke which leads to reduction in air pollution and health hazard to the rural women.

5. References

1. Anonymous. International Energy Agency Report, 2012.
2. Boafo-Mensah G, Ampomah-Benefo K, Bentumah Animpong MA, Owusu Oduro W, Neequaye Kotey E, Akufo-Kumi K, *et al*. Thermal efficiency of charcoal fired cook stoves in Ghana, Global Advanced Res J Eng Tech Innov. 2013; 2(3):102-110.
3. Bolaji BO, lalusi AP. Development of an Improved Coal Stove for Cooking in Developing Countries, AU J Techn, 2009; 12(3):182-187.
4. Bruce N, Perez-Padilla R, Albalak R. Indoor air pollution in developing countries: a major environmental and public health challenge, Bull World Health Organ. 2000; 78:1078-92.
5. Danshehu BG, Sambo AS, Musa M. Comparative performance of sawdust and wood-burning stoves, Niger J Renew Energy. 1992; 3(1, 2):50-5.
6. Duflo E, Greenstone M, Hanna R. Cooking Stoves, Indoor Air Pollution and Respiratory Health in Rural Orissa, Economic & Political Weekly. 2008; 43(32):71-76.
7. Kaoma J, Kasali GB. Efficiency and emission characteristics of two Zambia cook stoves using charcoal and coal briquettes. Reports in the Energy, Environment & Development (EE&D) Series-36, Stockholm Environment Institute (SEI) in collaboration with the Swedish International Development Cooperation Agency (SIDA), Stockholm, Sweden, 1994.
8. Rumchev K, Spickett JT, Brown HL, Mkhweli B. Indoor air pollution from biomass combustion and respiratory symptoms of women and children in a Zimbabwean village, Indoor Air. 2007; 17(6):468-74.
9. Venkataraman C, Raman P, Kohli S. Calorific value measurements for biomass fuels. Energy Environment Monitor. 1987; 3:63-67.