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Comparative Performance Evaluation of Bioethanol Stove and Alternative Cooking Technologies in Domestic Setting: Implications on Cost, Time and User Perception

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Abstract

Most households in Uganda use wood fuel for cooking and heating which poses numerous environmental and health hazards, hence leading to the desire for transition to alternative clean cooking solutions. Uganda Industrial Research Institute (UIRI) and Raising Gabdho Foundation (RGF) developed a bioethanol stove prototype for a typical household. Given the need for information on user perception and its comparison with other cooking alternatives for further improvement, this study presents a controlled cooking test which was conducted for performance evaluation of the prototype in terms of user perception, cost of cooking, and cooking time in comparison to Liquified Petroleum Gas (LPG), Electric Pressure Cooker (EPC), briquettes, and charcoal while cooking beans and '*posho*' for a family of four people by four cooks in triplicates. Controlled Cooking Test protocol from the Clean Cooking Alliance was adapted for the study, implemented, data collected and then analyzed using trimmed welch One-way ANOVA and Tukey HSD test in ASTATSA software. The cost of cooking using ethanol was significantly more than that for charcoal, EPC, and briquettes, but not significantly different from that for LPG. The time for cooking when using ethanol was not significantly different from that for EPC, LPG and charcoal, but it was significantly less than the one for briquettes. The bioethanol stove was easy to ignite, burnt with blue flame after regulation, cooked fast, and stable when mingling. However, it needed complete combustion at maximum stove power, reduction of ethanol fuel cost, elimination of sharp edges, and design modifications for grilling and to accommodate other saucepan sizes.

Keywords: E*thanol stove; cooking cost; cooking time; user perception; clean cooking; electric pressure cooker; controlled cooking test*

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Introduction

The usage of charcoal and firewood, the predominant cooking fuels (94%) in Uganda was estimated at 11,962,000 tons and 27,024,000 tons respectively in 2015 (Uganda Bureau of Statistics, 2020). Given the low wood to charcoal conversion efficiency of 10% and 15% charcoal loss during transportation and handling reported by National Environment Management Authority (2016), 167,753,411.8 tons of wood was used by households for fuel in the year 2015. If forest cover loss continues at this rate, Uganda shall have no forests left in the near future. Given the negative environmental and health effects of wood fuel, the government banned commercial production of charcoal in some parts of the country which in turn led to a desire for transition to alternative clean cooking solutions. However, there is limited technical information on comparative performance of the different clean cooking alternatives such as liquefied petroleum gas (LPG), electricity, biogas, briquettes and bioethanol. LPG is clean, but with very low uptake (0.05%) due to high refilling costs (Emitu, 2021). The use of electric pressure cookers (EPC) is convenient and affordable, but limited due to the low electricity access rate and the frequent blackouts (Naluwagga and Kiwana, 2020). Despite biogas being clean, convenient, and cheap in the long run, its rate of uptake is low due to high upfront cost and the dis-adoption rates are high due to lack of after sales services (Lwiza *et al.,* 2017). There is low uptake of briquettes attributed to variation in quality of briquettes among producers in Uganda due to the different methods of production, lack of technical knowledge and quality control procedures (Mambo, 2016). Ethanol fuel is a potential alternative to charcoal and despite the efforts made to increase its supply, there is limited preparedness in terms of appliances and programs to promote it (Ogwok *et al.,* 2022). In response to the scarcity of bioethanol appliances in Uganda, Uganda Industrial Research Institute and Raising Gabdho Foundation initiated a project aimed at development of a bioethanol stove. Having developed the first prototype, it was prudent to involve the user in the product development and understand the comparative advantages and probable challenges of cooking using the bioethanol stove (Zhang *et al.,* 2015). Stove performance can be tested using water boiling test, controlled cooking test and kitchen performance test. A controlled cooking test was preferred to water boiling test and kitchen performance test because it provides a cost-effective assessment of user feedback and performance comparison while preparing a common meal in a controlled environment (Hafner *et al.,* 2018). Therefore, this study presents a controlled cooking test which was conducted for performance evaluation of a bioethanol stove in terms of user perception, cost of cooking, and cooking time in comparison to other alternatives while cooking a common meal for a typical household in Uganda.

Materials and Methods

Description of test site

The controlled cooking test was done in a typical household kitchen at RGF premises in Kansanga, Kampala from 27th December, 2022 to 13th January 2023. The site was chosen due to convenience since it had a spacious kitchen, easily accessible by the study team and free of charge. Kansanga is located at latitude 0.29^{o} North, longitude 32.61^{o} East, and at altitude of 1232.00 m above sea level. The room temperatures during the test period ranged from 21^{o}C to 30^{o}C. The kitchen was well ventilated with a metallic window of 0.9m by 1.2m and a wooden door of 0.9m by 2.1m which were left open throughout the test period. It was also spacious enough (3m by 4m) to accommodate all participants without interference.

Description of Cooking Technologies and Fuels used

Alternative cooking technologies considered for the controlled cooking tests (CCT) included a bioethanol stove prototype of 3.73 kW stove power and 35 % thermal efficiency, electric pressure cooker (5 liters capacity, Saachi brand, Model: NL-PC-5301 and rated 900W), RGF charcoal stove size 2, single brass LPG burner screwed on 6 kg gas cylinder and pressurized aluminum cooking vessels of 5 liters capacity. The fuels used were liquefied petroleum gas (LPG) of Meru brand which comprises a mixture of propane and butane, carbonized stick briquettes containing some clay for long burn time sourced from RGF, charcoal sourced from Kansanga, Kampala, and bioethanol fuel of 94% alcohol content sourced from Bukona Agro Processors Ltd. The power consumption for the electric pressure cooker was measured using a plug-in power monitor EM561allosun (Voltage range: 90-260 V~, Max current: 10A and Max Power: 2600W).

Description of the cooking process

Controlled cooking test (CCT) protocol version 2.0 from the Clean Cooking Alliance was adapted for this study (Clean Cooking Alliance, 2004). The Clean Cooking Alliance, formerly known as Global Alliance for Clean Cookstoves is a non-profit organization supported by the United Nations Foundation to promote clean cooking technologies. Specific fuel consumption was not used as a measure for comparison since each technology considered used a different fuel. Instead, the cooking alternatives were tested for cost of cooking, user perception and total time required for preparing the same quantity of beans and posho for an average family of 4 people.

Four cooks (three ladies and one gentleman) were recruited, oriented about the controlled cooking test, shown how to use each of the cooking appliances, and then collectively engaged in the development of a common procedure for cooking beans and posho which was sufficient as a meal for a family of four people. They were allowed to practice cooking using the various appliances for two days before starting to collect data. The cooks agreed that a meal of beans and posho for a family of four people requires 0.75 kg of dry beans and 0.664 kg of maize flour. Every cook prepared three meals using each of the cooking technologies.

Cooking Procedure

Before commencing the tests, initial weight of fuel added, room temperature, and start time were recorded. In each test, dry beans were provided to the cook, sorted, washed and then soaked for at least 2 hours before boiling. Thereafter, they were cooked until they cracked. The boiled beans were fried using 5 table-spoonfuls of oil (Bidco Fortune Butto®) and an average of 350 g of ingredients comprising of 1 fresh tomato (150g), 1 fresh onion (85g), 1fresh carrot (55g), 1 fresh green paper (40g), and salt (20g). The sauce was allowed to boil until it formed a thick soup. Posho was prepared by boiling 10 cups of water (1.637 kg) and mingling with 5.5 cups of maize flour (0.664 kg). The end time and weight of fuel remaining were also recorded immediately after completion of the cooking process. Cooking time recorded included ignition time. In the events that power blacked out and came back, the system of EPC could not start from the previous point, but rather the whole task was restarted. Power consumption by the electric pressure cooker was read from a plug-in power monitor which was reading cumulative power consumption. The difference between the readings after and before the cooking task was the power consumption. Weight of charcoal left after cooking was subtracted to obtain the quantity used, and ethanol quantity was regulated as liquefied petroleum gas to adjust the amount of heat required during every stage of the cooking task. In addition to the quantitative dependent variables above, observations (difficulties encountered, amount of heat, stability of stove and tendency to smoke) when cooking with the different technologies were noted down and feedback was obtained from cooks after every task.

Data analysis

The data was cleaned, visualized using bar plots in Microsoft excel and checked for conformity to the assumptions for using ANOVA to assess significance of the differences in means. The populations did not have the same variance and the ratios of the largest to the smallest standard deviations, 3.78 for cooking cost and 2.44 for cooking time were more than the maximum recommended value of 2 for the variances to be considered close enough. Given the likely inaccuracies of type 1 error rates caused by unequal variances and sample sizes across groups, a trimmed Welch ANOVA was done to test whether there were statistically significant differences among the group means based on trimmed means (Celik, 2022). Tukey Honest Significant Difference (HSD) test was done as a post-hoc test to identify the pairs of cooking solutions which were significantly different from each other in terms of cost and time. ASTATSA online software version 2016 was used for the statistical analysis because it was free and easy to access (Vasavada, 2016).

Results

The unit costs of fuels used as of April 2024 in Kampala are tabulated below (Table 1). Six-kg LPG of Meru brand was at 49,000 which gives a unit cost of 8167 UGX/kg. Charcoal in a small container weighing 2.377kg was at 3,000 UGX which gives a unit cost of 1262 UGX/kg. Domestic electricity tariff in Uganda depends on the monthly consumption. Given the low consumption of EPC, the study assumed that each of the low-income households using it had a monthly electricity consumption of at most 80 kWh. The first 15 units cost 250 UGX/kwh, the next 65 units cost 805 UGX/kWh, Value Added Tax (18%), and a service fee of 3360 UGX per month give an average VAT inclusive and service fee inclusive electricity cost of 869 UGX/ kWh. Three liters of ethanol fuel from Bukona Agrochemicals weighing 2.432 kg was at 15,000 UGX which gives a unit cost of 6168 UGX/kg. Stick briquettes from RGF cost 1000 UGX/kg.

Table 1

Unit Cost of Fuels Used During the Controlled Cooking Test as Per April 2024

Particulars of fuel / energy source	Unit cost
Six-kg LPG	8167 UGX/kg
Charcoal	1262 UGX/kg
Average domestic electricity charges for at most 80 kWh per month (VAT and service charge inclusive)	869 UGX/ kWh
Carbonized stick briquettes	1000 UGX/kg
Bioethanol fuel (5,000 UGX/liter, Ethanol content > 94%)	6168 UGX/kg

The highest and lowest costs of cooking were UGX 2027 and UGX 770 when using Ethanol and charcoal respectively (Table 2). On the other hand, cooking using liquefied petroleum gas took the least time of 115 minutes whereas briquettes took the longest time of 210 minutes (Table 2). The standard deviations (SD) of cooking cost ranged (49-95) UGX and that for cooking time ranged (11-22) minutes. The number of trimmed data values (N) ranged from 8 to 11 per cooking fuel/ technology.

Table 2

The Trimmed Means and Standard Deviations of Cost and Time for Cooking with Different Energy Alternatives

Cooking Technology	Cost of cooking (UGX)	SD (UGX)	Cooking Time (Min)	SD (Min)	N
Charcoal	770	95	140	16	10
EPC	955	58	143	22	11
Ethanol	2027	71	126	11	8
LPG	1980	52	115	11	8
Stick briquettes	803	49	210	15	8

The means of cost and time for cooking beans and posho are shown in bar graphs for proper visualization (Figures 1&2).

The results of Trimmed Welch One-way ANOVA for assessment of significance of the differences in cost of cooking among the different cooking solutions give a p-value lower than 0.05, suggesting that the cost of cooking beans and posho for one or more cooking solutions are significantly different (Table 3).

Figure 1

Bar Graph Showing Means of Cost of Cooking

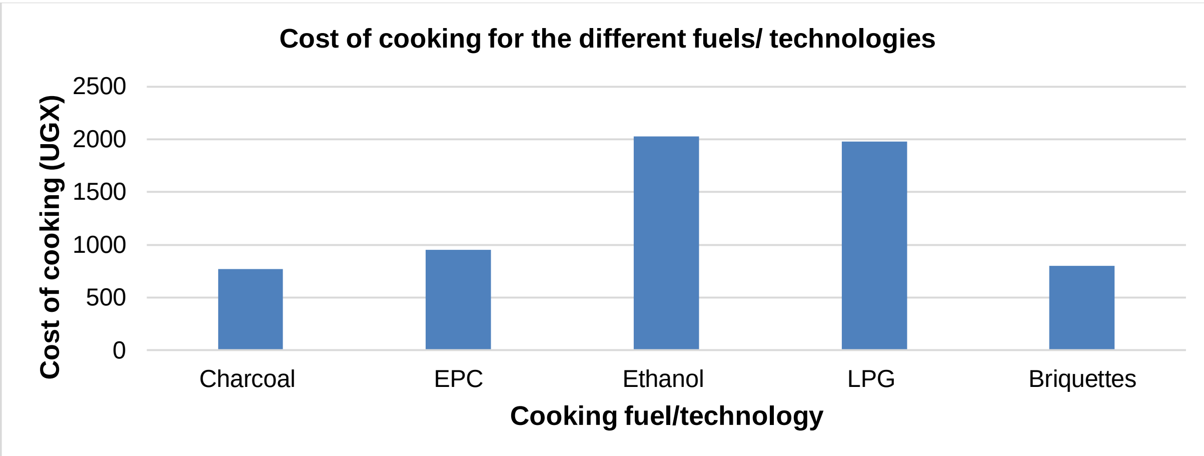

Figure 2

Bar Graph Showing Means of Cooking Time

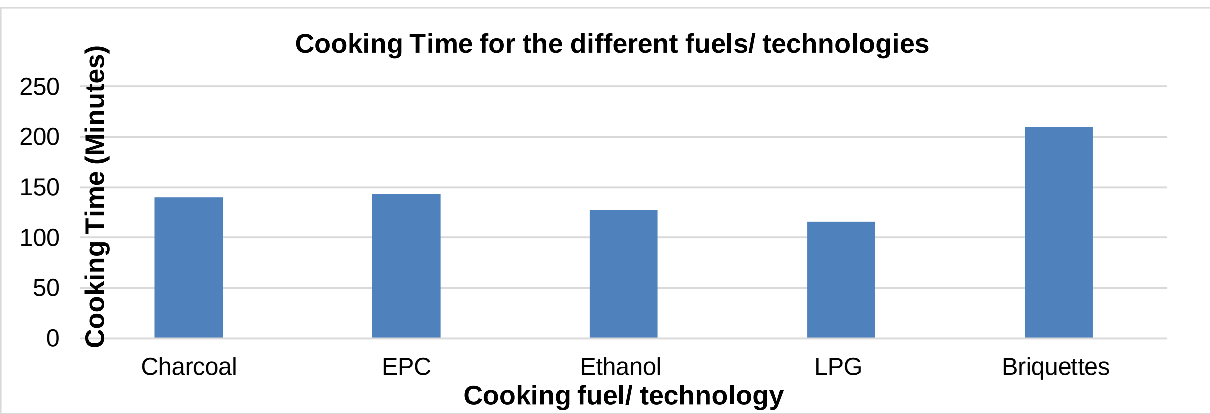

Table 3

Output From Trimmed Welch One-Way ANOVA For Cooking Cost

Source of variation	Sum of Squares	Degrees of freedom	Mean Square	F Statistic	p-value
Cooking solutions	13,939,218.83	4	3,484,804.71	752.64	1.1102e-16
Error	185,203.75	40	4,630.09		
Total	14,124,422.58	44			

In order to identify which of the pairs of cooking solutions were significantly different from each other, the summary of the results from Tukey HSD test is shown in table 4 below. The output in table 4 shows that the cost of cooking using charcoal was significantly different from that for electric pressure cooker ($p<0.05$). It therefore implies that the cost of cooking with charcoal and pressurized cooking vessel (UGX 770) was significantly cheaper than the cost of cooking the same meal using an electric pressure cooker (UGX 955). The cost of cooking with charcoal (UGX 770) is significantly cheaper than that for ethanol (UGX 2027) evidenced by p-value < 0.05 at 5% level of significance which is attributed to the high cost of ethanol (UGX 6168/ kg or 5000/ Liter) compared to the low cost of charcoal (UGX 1,262 / kg). Similarly, cooking with charcoal is also significantly cheaper than Liquefied Petroleum Gas (UGX 1980) shown by p-value <0.05 at 5% significance level which might have been attributed to the high refilling cost (UGX 49,000 for 6 kg cylinder). However, the cost of cooking using charcoal was not significantly different from that for briquettes (UGX 803) at 5% significance level (p-value > 0.05) because the briquettes were equally cheaper (UGX 1000/kg). Cooking with electric pressure cooker (UGX 955) was significantly cheaper than cooking with ethanol (UGX 2027) and liquefied petroleum gas (UGX 1980), but a little more expensive than cooking with briquettes (UGX 803) evidenced by p-values <0.05 in table 4 at 5% level of significance. The cost of cooking with ethanol was not significantly different from that of liquefied petroleum gas evidenced by p-value > 0.05, but it was significantly greater than that for briquettes (p-value <0.05) at 5% level of significance. The cost of cooking using liquefied petroleum gas was significantly greater than that for briquettes (p-value <0.05) at 5% level of significance

Table 4

Output From Tukey HSD Test for Cost of Cooking Using Different Cooking Solutions

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
Charcoal vs EPC	8.7761	0.0010053	** p<0.01
Charcoal vs Ethanol	55.0379	0.0010053	** p<0.01
Charcoal vs LPG	53.0059	0.0010053	** p<0.01
Charcoal vs Briquettes	1.4404	0.8266189	insignificant
EPC vs Ethanol	47.9322	0.0010053	** p<0.01
EPC vs LPG	45.8579	0.0010053	** p<0.01
EPC vs Briquettes	6.7820	0.0010053	** p<0.01
Ethanol vs LPG	1.9277	0.6361847	insignificant
Ethanol vs Briquettes	50.847	0.0010053	** p<0.01
LPG vs Briquettes	48.9193	0.0010053	** p<0.01

Note: ** = Significant at 0.01 level

Similarly, the p-value in table 5 of Trimmed Welch One-way ANOVA for assessing significance of the differences in cooking time among the different cooking solutions is lower than 0.05, suggesting that time required for cooking using one or more cooking solutions are significantly different.

In order to identify which of the pairs of cooking solutions registered significantly different cooking time from each other, below is table 6 showing summary of the results from the Tukey HSD test. The results show that the time for cooking using charcoal and a pressurized cooking vessel (140 minutes) was not significantly different from that for electric pressure cooker (143 minutes), and that for ethanol and a pressurized cooking vessel (126 minutes) as evidenced by p-values greater than 0.05. However, the time taken when using charcoal with a pressurized cooking vessel (140 minutes) was significantly more than that for liquefied petroleum gas and pressurized cooking vessel (115 minutes), but significantly less than that for briquettes and a pressurized cooking vessel (210 minutes) at 5% level of significance as shown by p-values <0.05. The cooking time when using electric pressure cooker was not significantly different from that for ethanol with a pressurized cooking vessel (p-value>0.05), but significantly more than that for liquefied petroleum gas with a pressurized cooking vessel (p-value < 0.05) and significantly less than that for briquettes with a pressurized cooking vessel (p-value < 0.05) at 5% level of significance. The time for cooking using ethanol with a pressurized cooking vessel was not significantly different from that for liquefied petroleum gas with a pressurized cooking vessel (p>0.05), but was significantly less than that for briquettes with a pressurized cooking vessel (p-value<0.05) at 5% level of significance. Cooking time when using liquefied petroleum gas was significantly less than that for briquettes at 5% level of significance (p-value<0.05). The findings therefore imply that cooking with ethanol was as fast as cooking with liquefied petroleum gas, electric pressure cooker and charcoal but much faster than cooking with briquettes.

Table 5

Output From Trimmed Welch One-Way ANOVA for Cooking Time

Source of variation	Sum of Squares	Degrees of freedom	Mean Square	F Statistic	p-value
Cooking solutions	43,676.9136	4	10,919.2284	41.5563	9.7256e-14
Error	10,510.2864	40	262.7572		
Total	54,187.2000	44			

Table 6

Output From Tukey HSD Test for Cooking Time Using Different Cooking Solutions

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
Charcoal vs EPC	0.5555	0.8999947	insignificant
Charcoal vs Ethanol	2.5796	0.3754135	insignificant
Charcoal vs LPG	4.6258	0.0177845	* p<0.05
Charcoal vs Briquettes	12.7784	0.0010053	** p<0.01
EPC vs Ethanol	3.1556	0.1892172	insignificant
EPC vs LPG	5.2445	0.0054139	** p<0.01
EPC vs Briquettes	12.5223	0.0010053	** p<0.01
Ethanol vs LPG	1.9412	0.6309008	insignificant
Ethanol vs Briquettes	14.5698	0.0010053	** p<0.01
LPG vs Briquettes	16.5110	0.0010053	** p<0.01

NOTE: * = Significant at 0.05 level, ** = Significant at 0.01 level

Observations and feedback from cooks

Charcoal

It takes long time to ignite, produces dirt in the hands when using, burns with high heat, stable for mingling, smokes especially when lighting, and does not allow for regulation of fire intensity. Participants realized that it was still possible to save on charcoal.

Liquefied Petroleum Gas

It is easy to ignite, clean and cooks faster. However, the participants raised the concerns of safety and cost.

Briquettes

They take very long time to ignite and burn with low heat intensity which prolongs cooking time. In addition, briquettes generated a lot of ash after cooking which was not pleasant. The cooks used some little charcoal during ignition of briquettes which also generated fumes. Participants liked briquettes for warming food after cooking due to their ability to burn longer with lower heat intensity than charcoal.

Table 7

Comparative performance of various cooking technologies (Cost, time and perception)

Cooking Technology	Cooking Cost (UGX)	Cooking Time (Min)	Perception
Charcoal	770	140	Smokes, dirty hands, stable
EPC	955	143	Clean, fast, convenient
Ethanol	2027	126	Ignites easily, fast, stable
LPG	1980	115	Ignites easily, fast, stable
Stick briquettes	803	210	Slow, low heat, high ash

Electric Pressure Cooker

It is clean, fast, convenient, and cheap to cook using an electric pressure cooker. However, participants reported the concern of power blackouts as experienced during the test period which may affect its uptake as a sole system for cooking. In the event that power blacks out and comes back, the system cannot start from the previous point, but rather the whole task is restarted which can lead to over cooking. Given the high poverty head count ratio at $2.15 a day of 42.1% for Uganda (World bank, 2024), they envision the challenge of high initial procurement cost for an ordinary Ugandan. Participants also complained of the cumbersome task of emptying and washing the cooking vessel for EPC during every task.

Pressurized cooking vessel

Participants observed that pressure cookers used less fuel and time compared to ordinary non pressurized aluminium cooking vessels which majority of Ugandans use.

Bioethanol

It was easy to ignite, burnt with a blue flame after regulation, and cooked faster. The ethanol stove was stable when mingling and allowed for adjustment of fire power which participants appreciated especially when low heat intensity is required towards completion of the cooking tasks.

Participants raised some concerns such as; the ethanol scent, irritation of their eyes while cooking, soot on the saucepan when flame was not regulated, possibility of losing the flame regulation cover, sharp handles of the fuel canister that cut some of the cooks during operation, inability of the stove to accommodate the smallest cooking vessels on the market and a family size pressurized cooking vessel of 8 liters capacity, inability of using the ethanol stove for grilling meat without affecting the food with ethanol scent, limited availability of ethanol in the market within Uganda, and the rising cost of ethanol which makes it very expensive as evidenced by the increase in cost from UGX 3800/liter during test period to UGX 5000/liter in 2024.

Discussion

Differences in cost of cooking

The study findings were not in agreement with Scott and Leach (2023) that the cost of cooking typical meals with an electric pressure cooker are less than 20% of the cost of cooking with charcoal. Their report suggests that if a meal costs UGX 770 to cook on charcoal, the cost of cooking the same meal should be less than UGX 154 which is not realistic in our context because boiling soaked beans alone using the electric pressure cooker consumed 0.235 kWh which translates to UGX 204.2. Given the fact that electric pressure cookers are optimized to work under pressure, the remaining task of frying the boiled beans and mingling posho during the test consumed 3.7 times the energy used for boiling beans. Their findings might have been based on another steaming task different from ours or else influenced by the variation in electricity tariff among the countries considered. For instance, their study reports that the cost of electricity in Uganda ($0.215/kWh) was 6.5 times the cost in Zambia ($0.033). Therefore, the cost of cooking the beans and posho using electricity in Zambia would be 146.9 UGX instead of 955 UGX in Uganda which agrees with their report. In addition, our study used a pressurized cooking vessel which was more energy efficient than an aluminum non pressurized saucepan and the remaining charcoal was reused later as opposed to other practices where the residual charcoal is left to burn to completion. The findings were in harmony with Armstrong *et al.* (2023) and Anozie *et al.* (2007) that cooking with ethanol could not be cheaper than cooking with biomass fuel (wood and charcoal). It can be attributed to the recent increase in the cost of ethanol fuel per litter from UGX 3800 to UGX 5000. Much as the findings agree with Scott and Leach (2023) that the cost of cooking with electric pressure cooker is less than that of liquefied petroleum gas, the cost of cooking with liquefied petroleum gas was twice that for electric pressure cooker, not thrice. The variation can also be explained by the different electricity tariffs in the countries.

Differences in cooking time

All the cooking alternatives used pressurized cooking vessels which reduced cooking time (Meric *et al.,* 2024). The faster performance of liquefied petroleum gas compared to other alternatives with exception of ethanol can be attributed to the high calorific value of 46.1 MJ/kg (Ihemtuge and Aimikhe, 2020). On the other side, briquettes took extremely long time to cook due to their low combustion rate (Haryanti *et al.,* 2021). This can be attributed to the high ash content in briquettes resulting from clay added during production.

Charcoal

Participants observed smoke when lighting the charcoal which is attributed to indoor air pollution that increases the incidence of respiratory diseases, cardiovascular diseases, DNA damage and CO poisoning, hence claiming a lot of lives (Idowu *et al.,* 2023). Participants recognized that it was possible to save on their cost of cooking with charcoal due to the good performance of RGF charcoal stove size 2 and the good cooking practices adopted during the test which minimized wastage.

Liquefied Petroleum Gas

Liquefied petroleum gas cooks faster because of its high energy density and ease to ignite. Users and distributors need to be trained on safety measures such as proper handling of the gas cylinder, lighting procedure (strike match before switching on the burner), checks for leakage, identification of genuine gas regulators, proper positioning of the gas stove (on a platform above the cylinder), switching off regulator after every cooking task and regular after sales services. The concern on cost requires incentives on gas and accessories in order to make it cost competitive.

Briquettes

The briquettes took very long time to ignite, burnt slowly with low heat intensity and generated a lot of ash because they contained clay which is incombustible and therefore served as a combustion retardant. The amount of clay added can be minimized to increase heat intensity and a briquette stove can be designed for enhanced combustion. Igniters can be made to enhance ignition and should be done outdoors to minimize indoor air pollution.

Electric Pressure Cooker

Electric pressure cookers are fast and cheap to cook because they cook under pressure with minimum waste of heat. They are convenient because the tasks are preprogrammed which therefore minimizes need for constant checking. The study recommends electric pressure cookers to be promoted alongside other clean cooking alternatives in order to help during moments of power blackout, improvement on the programmed system to allow memory of the previous task when power blacks out, the use of a loan scheme with long term repayment period as a way to address the challenge of high initial procurement cost of the appliance, and manufacturers to avail more cooking vessels for users who need them at an additional cost.

Pressurized cooking vessel

Participants observed that pressurized cooking vessels used less fuel and time compared to ordinary non pressurized aluminum cooking vessels which majority of Ugandans use. The savings in cost and time are attributed to the trapped steam, which fastens cooking, hence making them energy efficient.

Bioethanol

Suggestions for the concerns raised by the participants include; cooking with ethanol in a well-ventilated kitchen to minimize irritation of eyes, reduction of surface area of the canister openings to reduce evaporation of ethanol and burn with a blue flame at maximum stove power operation, fixing the cover for flame adjustment to minimize misplacement, covering the sharp edges with either wood or plastic material for safety of the user, design modification of stove size to accommodate the smallest cooking vessel and the family size pressurized cooking vessel (8 liters) without compromise on heat losses, design of a detachable grilling pan to ensure that grilled meat and fuel are not in contact and with a slight depression to minimize flow of water from the grilled meat into the fire, increase in ethanol distribution network by installation of ethanol fuel dispensers at nearby petrol stations to increase its availability, and regulation of ethanol pricing to ensure affordability.

Conclusion

The cost of cooking using ethanol was significantly higher than that for charcoal, electric pressure cooker, and briquettes, but not significantly different from liquefied petroleum gas. The cooking time when using ethanol was not significantly different from that for electric pressure cooker, liquefied petroleum gas and charcoal, but was significantly less than the one for briquettes. Participants appreciated the ease to ignite the ethanol stove, the burning with blue flame after regulation, fast cooking, and stability when mingling. Concerns raised for consideration in product improvement include irritation of eyes in confined kitchen, soot while cooking without flame adjustment, cuts by sharp edges, need for grilling meat without tainting it with ethanol scent, need for the stove to accommodate very small cooking vessels for singles as well as the 8-liter pressure cooker for large families, and need to enhance access for ethanol fuel. The study recommends cooking in ventilated kitchens to minimize irritation of eyes, reduction of ethanol vapour to ensure complete combustion at full power, covering sharp edges with heat resistant rubber, adjustment of stove dimensions to accommodate pressure cookers of 3 liters and 8 liters with minimum convective heat loss, development of an additional detachable component for grilling meat, and need for government incentives to enhance affordable ethanol fuel production and distribution. Finally, the study shows that proper use of the bioethanol stove with a pressurized cooking vessel had positive implications on perception of users and time savings in comparison to other cooking alternatives, but needs reduction in ethanol fuel cost to less than a dollar per liter to enhance affordability.

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