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# Toward energy saving and food safety in Central Mozambique: the role of improved cook stoves and heat retention boxes

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## Abstract

**Background:** Almost 80% of the population in sub-Saharan Africa relies on traditional biomass for cooking, which is typically associated with negative environmental, health, economic, and social impacts. Thus, many stakeholders, including development agencies and national governments in the Global South are promoting the use of the improved cookstove in order to save cooking time, save financial assets, maximize fuel efficiency, and reduce indoor air pollution. However, little attention is paid to the heating practices among households, which can determine food safety levels. Specifically, cooked food should be kept at temperatures above the danger zone (from 5 to 57 °C) prior to its consumption to prevent its contamination by bacteria and other unhealthy contaminants. In general, many studies address food preparation and storage separately, despite being complementary. In this study, we attempt to understand whether, the use of improved cookstove combined with heat retention box would result in improvements with regard to fuel and time saving, and adequate food storage temperatures. Furthermore, we examine the acceptability of food prepared with these two systems based on consumers' preference analysis. Involving 122 participants, the study was conducted in Gurué district, central Mozambique.

**Results:** The use of improved cookstove resulted in energy savings of 9% and 17% for cooking maize porridge and beans curry, respectively. The overall time consumption for cooking decreased by 14% (beans curry) and 24% (maize porridge). The use of heat retention boxes shows a better heat retention ability as compared to the locally used heat retention systems (leftovers, banana leaves).

**Conclusions:** The study concludes that improved cookstove is a sustainable mean for saving cooking time and fuel. Heat retention box has a potential to maintain adequate food storage temperatures. Both improved cookstove and heat retention box present a superior performance compared to traditional technologies; thus, can easily be diffused for not affecting the quality of food.

**Keywords:** Biomass energy, Foodborne illness, Time saving, Fuel saving, Gurué

## Background

Almost 80% of the population in sub-Saharan Africa (SSA)—roughly 780 million people—relies on traditional biomass for cooking [1, 2], which is typically associated with negative environmental, health, economic, and social impacts [3–8]. The traditional uses of biomass, for example, result in more than 600,000 deaths annually due to ambient air pollution in SSA [9, 10]. Beyond the

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indoor air pollution, gender-biased time [11] and physical burdens associated to fuelwood collection are additional health concerns, especially for females [12]. Women often have to carry heavy loads, e.g., 14–36 kg [13], which results in musculoskeletal pain [14]. As increasing time is spent on fuelwood collection, there is less time for other subsistence activities or recreation [15]. Moreover, the consumption of fuelwood increases the pressure on forest resources and the consequent forest degradation [16], which threatens the biodiversity conservation [17].

To reduce these negative effects, it is crucial to invest in more efficient and clean cooking technologies such as fuel-efficient cookstoves, since in Mozambique, for example, the current average efficiency of fuelwood use in three-stone-fires (TSF) is estimated to be around 10% [18], while the efficient cookstoves can reach efficiency levels of between 20 and 30% [19, 20].

In this context, many stakeholders, including development agencies and national governments in the Global South, are promoting the use of the improved cookstove (ICS) in order to reduce the adverse environmental, health, economic and social impacts associated with the traditional solid biomass. These stoves can be constructed of ceramic, mud, or metal [21]. In general, the disseminated stoves were primarily designed to maximize thermal and, thus, fuel efficiency [22] while reducing indoor air pollution [23, 24], although the current designs do not yet meet the World Health Organization air quality guidelines [25]. Moreover, other more advanced stove designs also exist [26]. Associated advantages, such as (potentially) reducing deforestation and forest degradation, saving cooking time, and saving financial assets to purchase fuels are connected to the use of the ICS [27–29]. Yet, the total replacement of traditional stoves in developing countries remains far from reality [30].

There are several test protocols to assess the performance of the ICS. Some are laboratory-based, e.g., water boiling test (WBT) [31], while others are field-based, e.g., kitchen performance test (KPT) [32]. The controlled cooking test (CCT) was developed as a mix of these approaches [33]. It allows for comparing traditional stoves with ICS regarding fuel consumption and cooking time under controlled conditions [34]. Moreover, it is recommended for testing stove performance when the aim is to understand how stoves perform with local foods, fuels, and cooking practices [35].

From a health perspective, while it is important to reduce particle emissions during the cooking process, thus lowering indoor air pollution [36], on the other hand it essential enhance the digestibility, taste, texture, and shelf-life of food [37]. Latter is particularly ensured by access to potable water, adequate food handling and storage conditions, adequate sanitation and hygiene

[38]. Thus, it is also critical to look beyond food preparation as, for example, the heating practices and storage of cooked food at ambient temperature for extended periods can determine the level of food safety [39], a very serious but neglected health problem. In this study, we refer to food safety as actions aimed at protecting foods from biological and physical hazards that may occur during preparation and consumption [40]. By heating food, the multiplication of pathogenic microorganisms and, therefore, food-borne illnesses—which have an economic loss from deaths of approximately 39 billion USD in SSA [41]—can be reduced [42]. In fact, the health burdens caused by food-borne diseases in SSA are comparable to malaria, HIV/AIDS and tuberculosis [41]. According to Ricci et al. [43], food should generally be maintained at temperatures below 5 °C or above 60 °C, to avoid the so called “temperature danger zone” (from 5 to 57 °C [44]) in which pathogenic microorganisms grow quickly. To keep cooked food at temperatures above this danger zone, technology that can retain thermal energy at least for some time is needed. The alternative of maintaining temperatures below 5 °C through refrigeration is challenging in rural Mozambique because access to electricity remains low: only 5.7% of the population has access to electricity in rural areas [45]. Furthermore, people in rural areas may be very unlikely to warm their food before consumption, after it cools down [46]. A promising solution to this challenge is the use of heat retention systems (HRS), here defined as systems that can temporarily hold thermal energy in the form of hot substances for later use [47]. The advantages of these systems include keeping food at temperatures above 60 °C for several hours after the cooking pot is taken off the heat source. Furthermore, some of these systems can easily be manufactured and all that is required is to place the pots inside [48]. Therefore, combining ICS with HRS can lead to very positive results in terms of energy savings [49] and the prevention of foodborne illnesses [50]. However, the use and suitability of HRS in rural areas is poorly documented.

Although several (meta-)studies analyze the performance of different ICS designs [28, 51–54], there are very few analyses on the lapse of time between the food being ready and its actual consumption, especially in rural areas of developing countries [49]. Only a limited number of studies, including Tiffany et al. [55] and Kaushik [56], assess the performance of HRS, especially those designed for domestic use in rural areas of developing countries. There is still no standardized test protocol for domestic HRS. The commonly applied method to evaluate the performance of an HRS is by monitoring temperature change inside the HRS for a certain period [55, 57]. In addition, studies generally address food preparation and handling separately, despite being complementary.

It could be argued that positive health and environmental effects are enough for ICS and HRS implementation. However, sensory and function factors are essential for acceptance and adoption of the respective technologies [58]. Familiar taste, texture, and appearance are the primary goals for the consumers [59]. As found by Malakar et al. [60] and Wang et al. [61], for example, people may find food cooked with firewood in traditional stoves more tasty compared to that cooked in improved cooking stoves and fuels, since smoke may infuse food with distinctive flavor [59]. Therefore, in this study, we focus on two essential aspects. First, we attempt to understand whether, given the local conditions and prevailing cooking practices, the use of ICS combined with HRS would result in improvements with regard to fuel and time saving, and adequate food storage temperatures. Secondly, we examine the acceptability of food prepared with these systems based on consumers' preference analysis. The results of this study present a more holistic view of the necessary interventions to reduce cooking energy consumption and increase food safety in poor and rural areas.

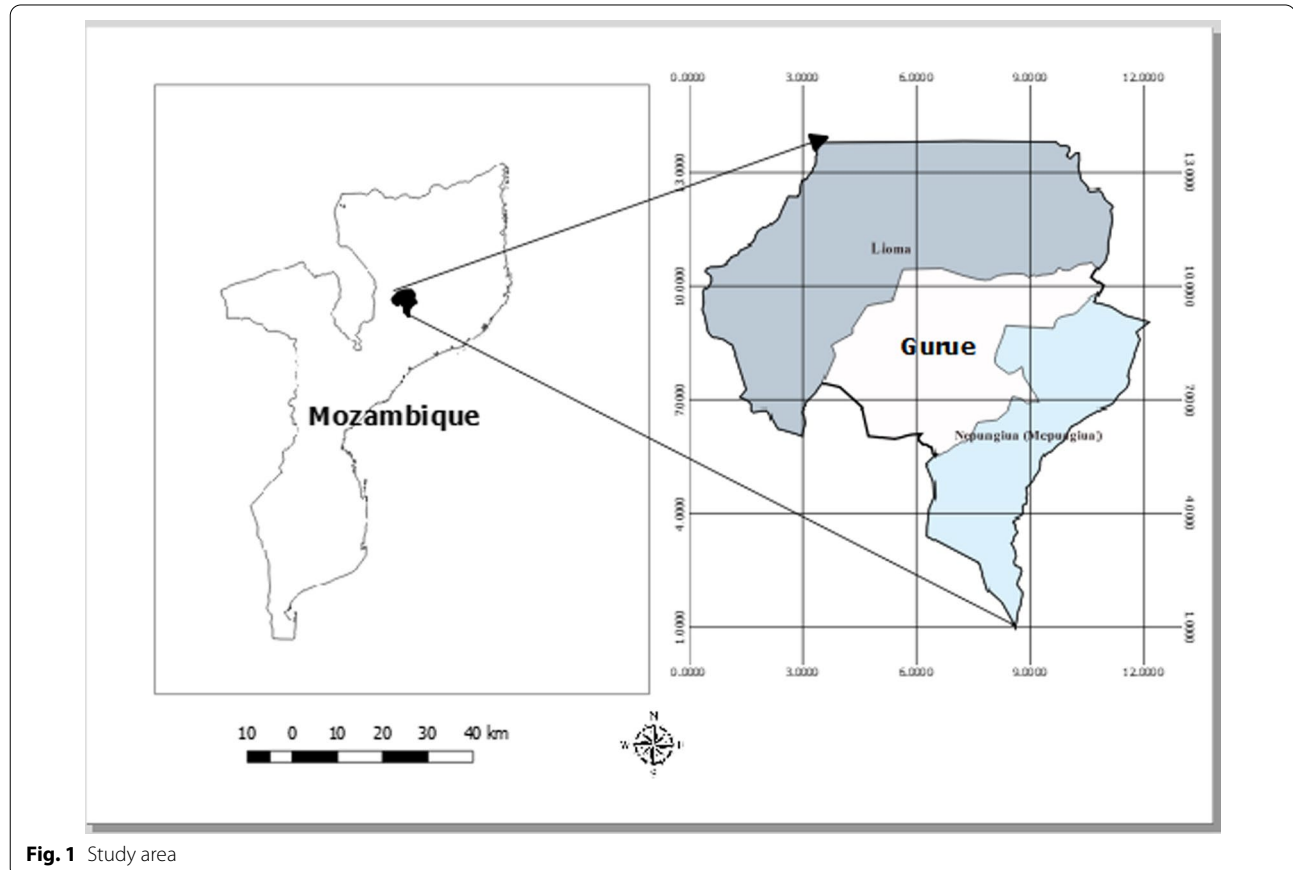
## Methods

### Study area

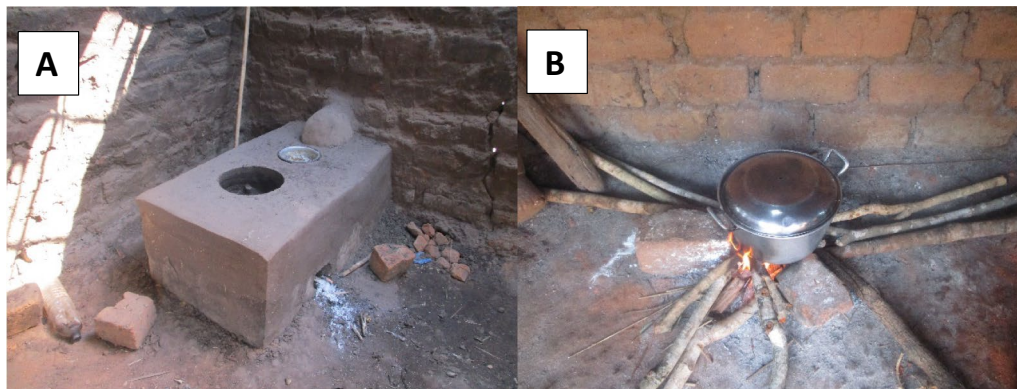
The study was conducted in six different communities (Mocha, Mulapane, Nauouoro, Muranuco, Sewere and Muala Oripa) in Gurué district of central Mozambique, where the majority of population use TSF to prepare their meals (Fig. 1). The district borders of the Republic of Malawi lay between the latitudes  $15^{\circ} 18' 55.2''$  S and  $36^{\circ} 54' 45.6''$  E. It occupies a total area of  $5646 \text{ km}^2$  and the population is estimated at 431,000 inhabitants, which corresponds to a population density of 76 individuals per  $\text{km}^2$  [62, 63]. The main activities are subsistence agriculture and animal husbandry [63].

### Performance of the ICS

Field testing is an important step toward acceptability of an ICS [32, 64]. We conducted CCT between June and December 2020, using both ICS and TSF in order to analyze how efficient ICS is compared to TSF (Fig. 2). A total of 12 non-portable mud-ICS was constructed—2 in each area—and were located inside the kitchens of the local leaders' houses. The stove design used in this study was based on the ICS implemented in Idifu village, Tanzania



**Fig. 1** Study area



**Fig. 2** A Improved biomass cook stoves; B three-stone stoves

**Table 1** Design features of the ICS

Construction features	Dimensions
Stove height	40 cm
Length of the stove body	107 cm
Width of the stove body	56 cm
Wood entry slot and combustion chamber	12 X 12 cm
Diameter of the smaller saucepan	16 cm
Diameter of the bigger saucepan	26 cm
Diameter of the chimney	12.5 cm

**Table 2** Food used in the CCT

Dish	Ingredients	Ingredients weight (g)
Bean curry	Beans	500
	Carrots	64
	Onion	43
	Tomato	205
	Water	3000
Xima	Corn flour	800
	Water	2750

[65], as it is proven successful under field conditions. The design features of the ICS are presented in Table 1.

We follow Bailis et al. [66] testing protocols on CCT to compare the performance of ICS to TSF in standardized cooking tasks. The cooking task consisted of cooking two types of food regularly consumed in the community, namely, bean curry and *xima*, a type of maize flour porridge locally consumed; this is also known as *ugali* or *nsima* in other regions of East Africa (e.g., Kenya and Tanzania). To ensure that the tests were uniform, not only did we use locally available fuels and pots, but the quantity of ingredients were also equivalent to those regularly used in a household, jointly agreed upon with the villagers during an initial village meeting (Table 2).

Prior to the tests, the cooks (mainly female) who prepared the food were trained and allowed to use ICS several times (within one month) in order to gain experience on how to operate the ICS and ensure that any water remaining in the stove evaporates, so that the ICS were dry enough to be tested. This was done to avoid potential bias, given the fact that the individuals who normally cook in the households did not have any experience with ICS at the time of the experiment. To ensure that the CCT protocol was precisely followed, the tests were supported by an assistant, who interfered only to a

minimum amount and only to safeguard testing protocols. The cooking tasks were identically performed for both ICS and TSF. For both ICS and TSF, the beans were cooked first, then the maize flour porridge. The end of the cooking tasks was defined as the points in time when the beans could be mashed easily between two fingers or with a fork and when the *xima* had a consistency in which one could stick a knife and it could stay upright without falling. Both definitions reflect daily reality in the study villages.

The fuelwood consisted of a mix of five species commonly used in Gurué (*Swartzia madagascariensis*, *Julbernardia globiflora*, *Parinari curatellifolia*, *Pterocarpus angolensis* and *Uapaca kirkiana*). Before the CCT, wood was sun dried for 7 days to lower the moisture content (MC), as commonly practiced by the study area residents. A digital Wood Hygrometer model MD-2G was used to measure wood moisture content. It has two sensor pins at the top that were pushed into the wood to determine the percentage value of the water content. The average value of MC was 12%. At the end of the cooking task, the unburned wood and the leftovers were removed and weighed directly.

After the CCT, measurements were used to calculate performance indicators (cf. Hafner et al. [67]). We



calculated the total fuelwood consumed ( $\Delta f$ ) by the difference between the final fuelwood ( $f_f$ ) and the initial fuelwood ( $f_i$ ). The weight of ingredients ( $W$ ) was calculated by adding the type of ingredient ( $C_i$ ) used in grams. The total cooking time ( $\Delta t$ ) is the difference between the final time ( $t_f$ ) and the initial time ( $t_i$ ) of the cooking process. The respective formulas are presented in Table 3. A Mann–Whitney  $U$  test was used to determine if there is significant difference in mean fuelwood consumption between TSF and ICS.

**Performance of heat retention systems**

Locally used HRS were tested against a newly implemented system, the heat retention box (Fig. 3). There are two techniques used at the study site to retain heat in the food. One technique is to cover the hot cooking pot with banana leaves (BL) to keep food warm until serving time, the other is keep the pot on the stove to use the leftovers (LO) from the cooking process. The newly implemented system is a heat retention box (HRB), which can easily be manufactured at relatively low cost. It is insulated with layers of PE foam and aluminum foil facing toward the hot cooking pot [48]. Each HRS was tested two times in each community and 20 to 21 households per community were involved.

After the cooking sections, 300 g of beans and 500 g of *xima* were immediately transferred to each of the heat retention systems. The initial food temperature was measured, then for the next 6 h, temperature changes were recorded every 30 min [55, 57], using a temperature

data logger. The amount of time the system can hold the food at above 60 °C was determined.

The length of time before food temperature falls below 60 °C was the performance indicator used for HRS. We used one-way analysis of variance (ANOVA) followed by Tukey test for multiple comparisons to compare the different HRS performance as we wanted to examine whether there was a difference between the mean of all possible pairwise comparisons [68]. The data were normally distributed and presented equal variances according to Shapiro–Wilk and Bartlett’s tests ( $p_{\text{value}} > 0.05$ ).

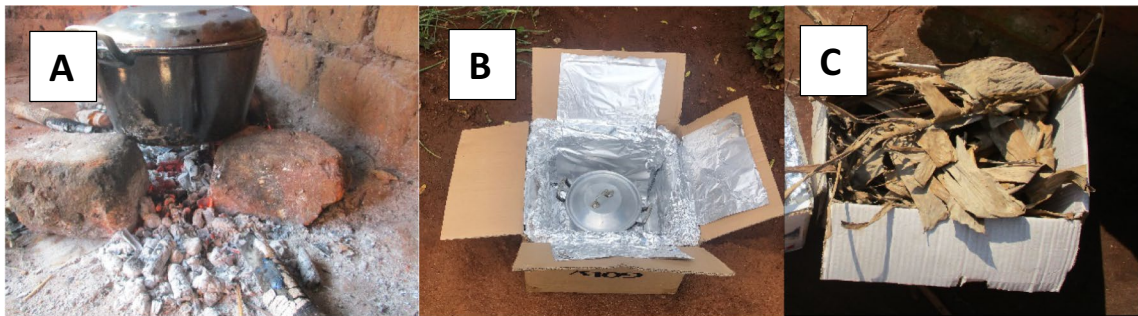
**Consumers’ preferences**

Consumer acceptability tests were conducted [69, 70] using the method of central location test [71]. We tested acceptability of food from (1) only TSF, (2) only ICS, (3) TSF and LO, (4) TSF and BL, (5) TSF and HRB, (6) ICS and LO, (7) ICS and BL, and (8) ICS and HRB. A total of 122 participants were randomly chosen for the tests. In two of the testing areas, we had 21 participants each and in the remaining 4 areas we had 20 participants.

Food items were kept in heat retention systems until ready for serving, defined as the absolute time between the end of the cooking task and actual food consumption, jointly defined with the villagers. The consumer preference tests included representatives of selected households (preferably the heads of households) who did not have prior knowledge about which stove was used to cook the food they were about to taste. The participants were asked to maintain some distance from each other and not to communicate during the session. Every participant tasted a portion of the cooked food and evaluated the acceptability of food in terms of taste, texture, aroma, color, and overall acceptability [72], according to a 5-point Likert scale (1 = dislike very much, 2 = dislike, 3 = neither like nor dislike, 4 = like, 5 = like very much). Prior to tasting, all participants were explained the meaning of the food attributes, e.g., texture is the “the visual or tactile characteristics and appearance of the food”.

**Table 3** Stove performance indicators

Indicators	Formulas	Equation no.
Total fuelwood consumed (g)	$\Delta f = f_f - f_i$ (1)	
Weight of ingredients (g)	$W = \sum_{i=1}^n c_i$ (2)	
Total cooking time (min)	$\Delta t = t_f - t_i$ (3)	



**Fig. 3** Means of heat retention: **A** leftover charcoal; **B** heat retention box, **C** banana leaves

**Table 4** Average values of fuel and time consumption for different types of food and stoves ( $n = 12$ )

Type of food	Type of stove	$\Delta t$ (min)	$\Delta f$ (g)
Beans	ICS	77.50	7094.72
	TSF	89.72	8512.50
	Diff (TSF-ICS)	12.22 <sup>a</sup> (14%)	1417.78 <sup>a</sup> (17%)
Maize flour porridge	ICS	20.61	4978.28
	TSF	27.17	5448.89
	TSF-ICS	6.56 <sup>a</sup> (24%)	470.61 <sup>a</sup> (9%)

<sup>a</sup> Differences are significant at a level of significance of 0.05

To analyze the consumers' preferences, we computed frequency distribution (percentages of responses) of the Likert scale categories (dislike very much, dislike, neither like nor dislike, like, like very much). Given that we wanted to investigate people's preference of the foods from different combinations of ICS and HRS, Chi-square tests of independence were used to examine the extent to which the different types of ICS and HRS influenced the respondents' perceived food attributes.

## Results

### Performance of the ICS

The results in Table 4 are the average values of fuel and time consumption for different types of food and stoves. These results indicate that, as compared to TSF, ICS consume less fuelwood and time ( $p_{\text{value}} < 0.05$ ). TSF presented higher overall means for the calculated variables, namely, total fuelwood consumed and total cooking time ( $\Delta t$ ). ICS reduced time and fuelwood consumption by 14% and 17% during beans cooking, respectively. During maize flour porridge cooking process, the ICS saved 24% of time and 9% of fuelwood.

### Performance of heat retention systems

Tests were carried out to measure the time that food within the HRS took to lose heat until it reached 60 °C. Two locally used HRS, namely, the use of leftovers (LO) and banana leaves (BL) were tested against heat retention box (HRB) (Fig. 5). Table 5 shows that the temperature decrease is slower in the HRB when compared to LO. For both meals, HRB took 160 to 175 min to reach 60 °C, whereas LO took less than 140 min to reach the temperature danger zone. Although the absolute values indicate that BL was in an intermediate position, BL are not statistically different from both LO and HRB.

**Table 5** Average time (min) the food temperature took to reach 60 °C

	Bean curry ( $n = 12$ )		Maize flour porridge ( $n = 12$ )	
	Mean time (min)	Std. dev	Mean time (min)	Std. dev
HRB and ICS	170 <sup>a</sup>	24.5	160 <sup>a</sup>	24.5
HRB and TSF	175 <sup>a</sup>	22.6	175 <sup>a</sup>	12.2
BL and ICS	145 <sup>ab</sup>	12.2	140 <sup>ab</sup>	15.5
BL and TSF	150 <sup>ab</sup>	19.0	145 <sup>ab</sup>	12.2
LO and ICS	115 <sup>b</sup>	12.2	105 <sup>b</sup>	16.4
LO and TSF	135 <sup>b</sup>	25.1	120 <sup>b</sup>	12.3

Means followed by the same letter (a or b) within a column are not significantly different by the Tukey-test at a level of significance of 0.05

### Consumers' preferences

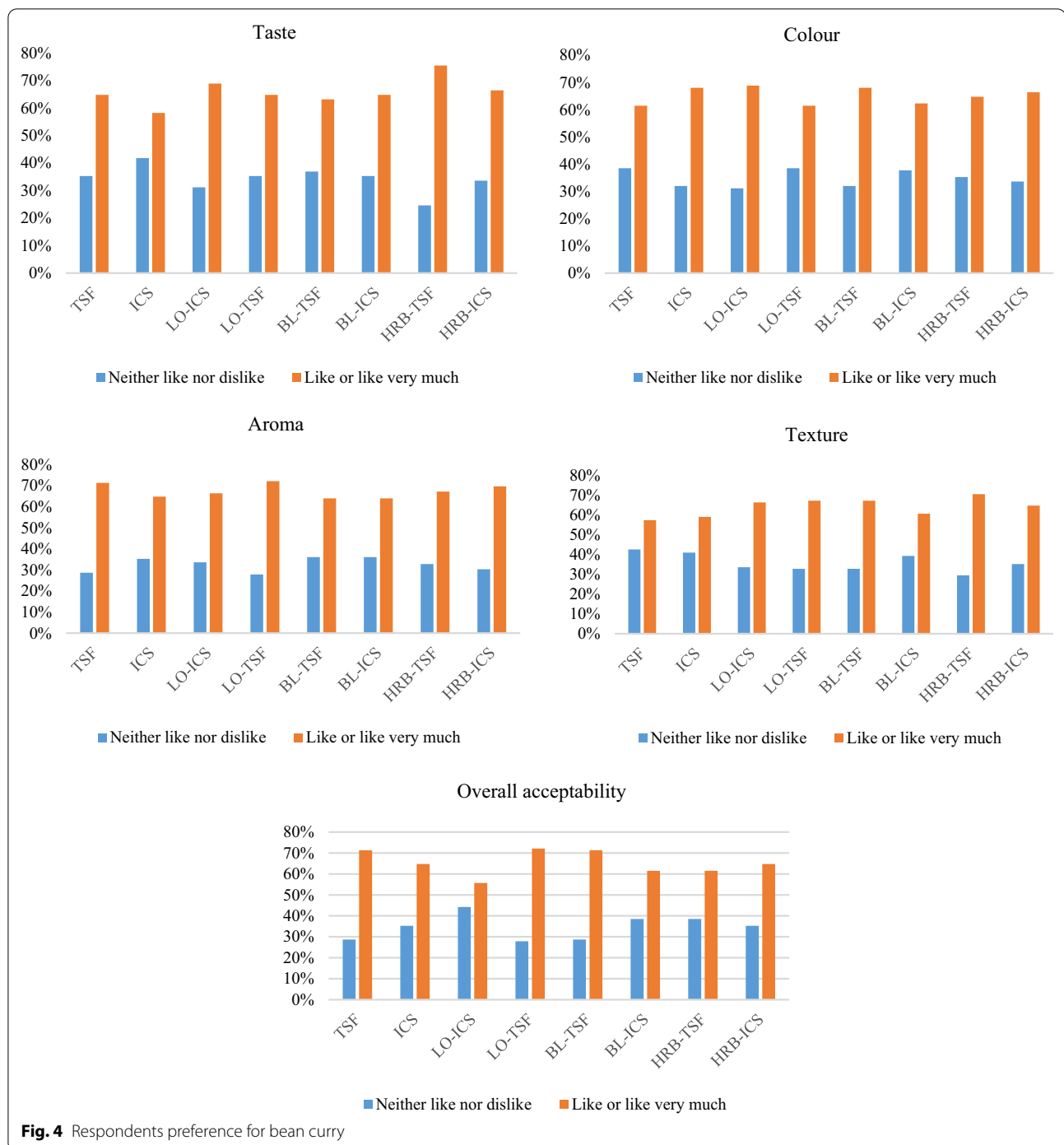
The results presented in Figs. 4 and 5 show that most of the consumers "like" or "like very much" the food from any of the stoves or HRS. None of the respondents said that they did not like the tested food attributes. However, some respondents reported a neutral position (23 to 44% depending on the type of stove or HRS). The Chi-square test of independence does not indicate a relationship between the type of stove or HRS and the preference for food ( $p_{\text{value}} > 0.05$ ).

## Discussion

We use CCT and heat retention tests to estimate the performance of ICS and HRS. The use of ICS resulted in time and fuel savings. The use of HRB showed a better heat retention ability as compared to locally used HRS.

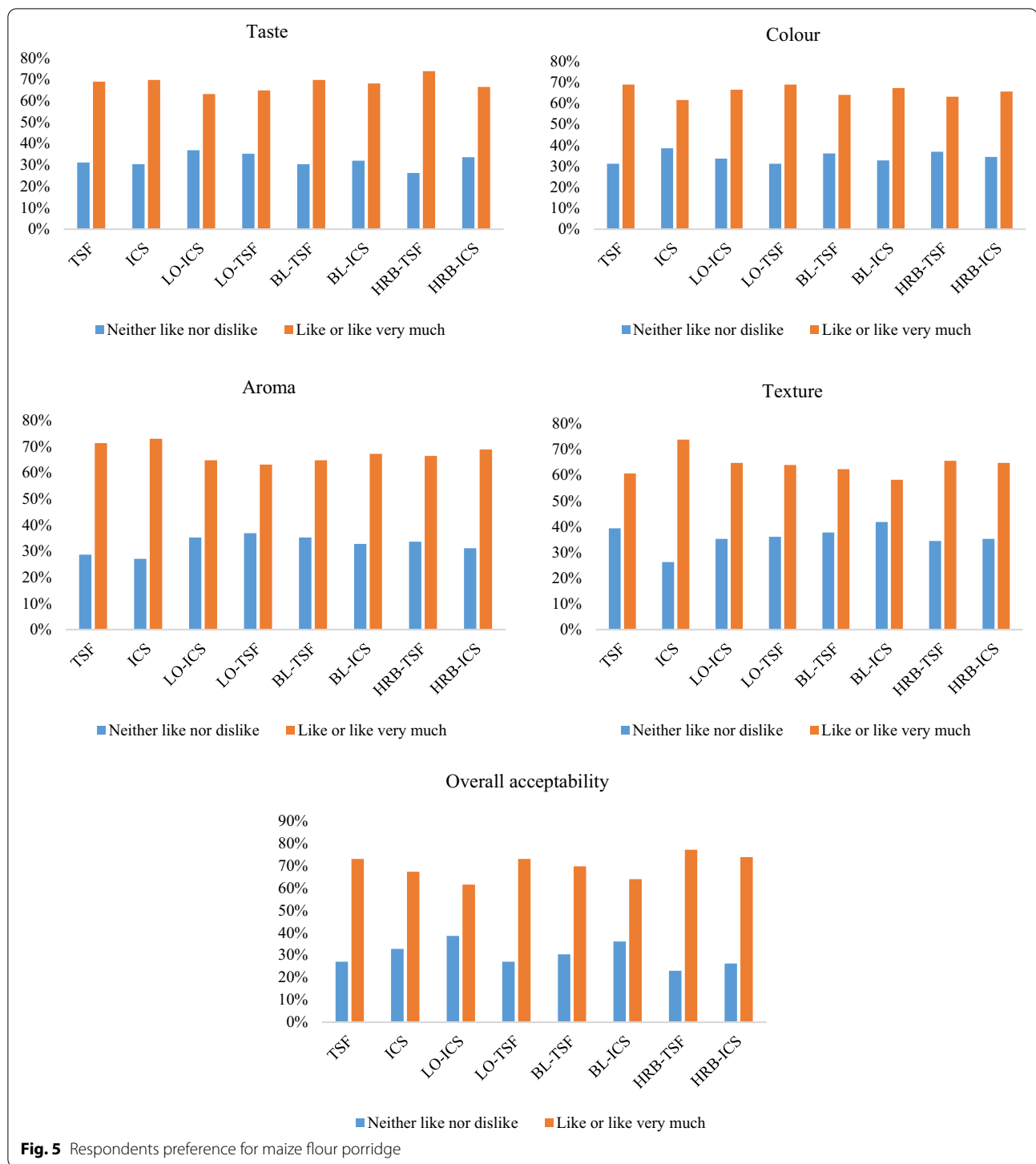
Like KPT, CCT also has the advantage of predicting stove performance during real use [33]. Nevertheless, the variability in the results is high as compared to WBT due to real world differences in user behavior and types of fuelwood, etc. [73]. CCT is a relevant method because it has a lower level of variability when compared to KPT, while allowing a certain level of repeatability given that it is performed under controlled conditions. As such, the results of the current study offer insights on mud-ICS's ability to reduce time and fuel consumption as compared to TSF.

The ICS model used in the present study is of easy construction and replication in the conditions of the study site due to not just its low costs, but also the easy availability and handling of required construction materials. However, despite being statistically significant, the rate of fuel savings found in this study is relatively low when compared to those found in other studies [34, 74, 75]. Negash et al. [75], for instance, report fuel savings of 32% in a non-transportable mud stove as compared to the



TSE, whereas we found fuel saving of 9% and 17%. This may be due to the energetic properties of wood species used in the study area [76] and the site conditions [77]. In fact, properties such as water content and density can determine the amount of fuelwood needed for a cooking task [33, 78]. High-density solid fuels, for example, have more mass per volume available for burning [79].

Moreover, the cooks' experience may also be another factor for the low rate of fuel savings. Cooks use less fuel and cook more quickly over time [34], but in this study the cooks only had about a month to become familiar with the ICS; perhaps a longer time period would have increased saving rates regarding time and fuel used.



The average savings in cooking time were 6.6 min and 12.2 min (14% and 24%) for beans and maize flour porridge, respectively. This might show that the performance is likely to be different depending both on the food item and on the quantity of food cooked [34]. In addition, ICS

performance also depends on the number of pots. For a single pot, TSF have higher efficiency over ICS while ICS is superior to TSF when cooking with two pots simultaneously [80]. It is noteworthy that the stove used in this study was designed to prevent direct exposure to smoke,



which is likely to lead to an improvement in the indoor air quality of the kitchen area [81, 82].

Food is not always consumed immediately after cooking; thus, we secondly evaluated HRS's ability to keep food above temperature danger zone before consumption. The tests results indicate that the loss of temperature inside the cooking pot is more pronounced in LO, possibly due to the lack of insulation of the pot against exposure to wind. Thus, it can be concluded that HRB results in less heat losses during the lapse of time between the food being ready and its actual consumption because HRB is insulated with layers of PE foam and aluminum foil, which gives it a comparably better heat retention capacity [83]. As a result, HRB may have the ability to inhibit the multiplication of microorganisms, which ultimately increases food safety. However, the results of this study were lower compared to those found by Kaushik [56], who found average heat retention time of more than 300 min. This was probably due to the type and amount of food. While Kaushik [56] tested the HRS with 300 g of rice and 990 ml of water, we used 800 g of corn flour and 2750 ml of water. Moreover, in the study context, we were unable to observe and compare the microorganism growth between the different HRS, which would allow us to obtain evidence of the effectiveness of HRS in preventing the multiplication of microorganisms.

It is important to note that LO depends very much on the amount of fuelwood that remains after the cooking process; therefore, it also depends on the type and initial amount of fuel used for cooking. A small initial amount of LO might contribute to the rapid heat losses. LO had the same efficiency as BL, but the latter does not need fuelwood; hence, it can be recommended as a replacement for LO given its potential to reduce fuelwood consumption. The use of BL as insulation material is also not statistically different from HRB. Nevertheless, BL, as an organic material, is easily degradable and must be replaced frequently due to its poor durability. HRB is made of a more durable material (aluminum foil and foam), making it more suitable for domestic use. In the context of our study area, people generally consume the maize flour porridge while it is still hot [84]. When it becomes cold, it is usually discarded since its typical consistency changes with cooling and its heating becomes difficult. In general, as suggested by Taalo et al. [46], many poor people in rural areas may be very unlikely to warm their food before consumption, after it cools down. Therefore, the use of HRB may also help to reduce food waste.

This study also aims to test consumer preferences to sensory food features. Therefore, we also conducted food preference tests to assess the acceptability of different combinations of cooking systems (TSF and ICS) and

HRS (LO, HRB, BL). Our results show that most of the consumers "like" or "like very much" the sensory food features regardless of the stoves or HRS. Thus, the use of the newly implemented technologies, ICS and HRB, does not negatively affect food acceptance given that textural properties of food are an important factor for adults' food acceptance [85] and the willingness to try [86]. As pointed out by Leng et al. [58], a crucial aspect in modifying cooking technology is to consider the sensory characteristics of food, as this is essential for adoption of the respective technology. Ignoring the preferences of the potential users will most likely lead to an underutilization of the technologies [87]. A study investigating the links between food preferences and food choices shows that sensory and functional factors have a much stronger impact on the selection of food than health and price [88]. In fact, sensory perceptions often tend to be less negotiable than other values, with these perceptions including taste, texture, odor, or appearance [89]. Nevertheless, the use of 5-point Likert scale may promote social desirability bias [90], as respondents may use the midpoint to avoid selecting socially undesirable options [91]. In this study, we tried to avoid this issue by clearly explaining the survey items as suggested by Kulas et al. [92]. Studies demonstrate the reliability of 5-point Likert scale as compared to other approaches [93–95].

In future studies, evidence on reduction of time for fuelwood collection and the health benefit of the stove design with regard to indoor air pollution reduction should be provided. In addition, the relationship between HRB and microbial growth needs further examination.

## Conclusion

We use CCT and heat retention tests to estimate the performance of ICS and HRS. Additionally, we conducted consumers' preference analysis to evaluate the acceptability of food from these technologies. The use of ICS resulted in fuel saving of 9% and 20% for maize porridge and beans, respectively. The overall time consumption for cooking decreased by 14% (beans) and 24% (maize porridge). The HRB took 160 to 175 min to reach temperature danger zone" (from 5 to 60 °C) in which pathogenic microorganisms grow quickly, whereas LO took less than 140 min and BL took 140 to 150 min. Thus, the use of HRB showed a better heat retention ability as compared to LO. In addition, the introduction of ICS and HRB did not statistically and significantly affect food acceptance. Therefore, the study concludes that although the rates of fuel savings found in this study is relatively low compared to other studies, ICS is a sustainable mean for saving cooking time and fuel. HRB has a potential to maintain adequate food storage temperatures. Both ICS and HRB present a superior performance and can easily be diffused

for not affecting the quality of food. These technologies can be manufactured using locally available materials and are suitable for energy-poor communities. Further studies are needed to provide evidence on factors like fuelwood collection time and indoor air pollution reduction. In addition, HRS ability to reduce microbial growth need further examination.

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#### Author contributions

CEM conceptualized and designed the work, collected the data, analyzed and interpreted the data and drafted the manuscript. JMH interpreted the data and critically revised the manuscript. HH conceptualized and designed the work and critically revised the manuscript. GU interpreted the data and critically revised the manuscript. JM interpreted the data and critically revised the manuscript. CR conceptualized and designed the work and critically revised the manuscript. SS substantively revised the manuscript. All authors read and approved the final manuscript.

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#### Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

#### Declarations

##### Ethics approval and consent to participate

The authors had permission from the local administrative authorities to conduct the study. Informed consent was obtained from all individual participants included in the study.

##### Consent for publication

Not applicable.

##### Competing interests

The authors declare no competing interests.

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