Matavel et al.
Energy, Sustainability and Society (2022) 12:26
https://doi.org/10.1186/s13705-022-00352-6

Energy, Sustainability and Society

ORIGINAL ARTICLE

Open Access

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

Custodio E. Matavel[1,2*], Johannes M. Hafner[1,2], Harry Hoffmann[1], Götz Uckert[1], Jonas Massuque[3], Constance Rybak[1] and Stefan Sieber[1,2]

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

*Correspondence: custodio.matavel@zalf.de

[1] Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, 15374 Müncheberg, Germany
Full list of author information is available at the end of the article

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 temporary 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° 18′ 55.2″ S and 36° 54′ 45.6″ E. It occupies a total area of 5646 km^2 and the population is estimated at 431,000 inhabitants, which corresponds to a population density of 76 individuals per 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

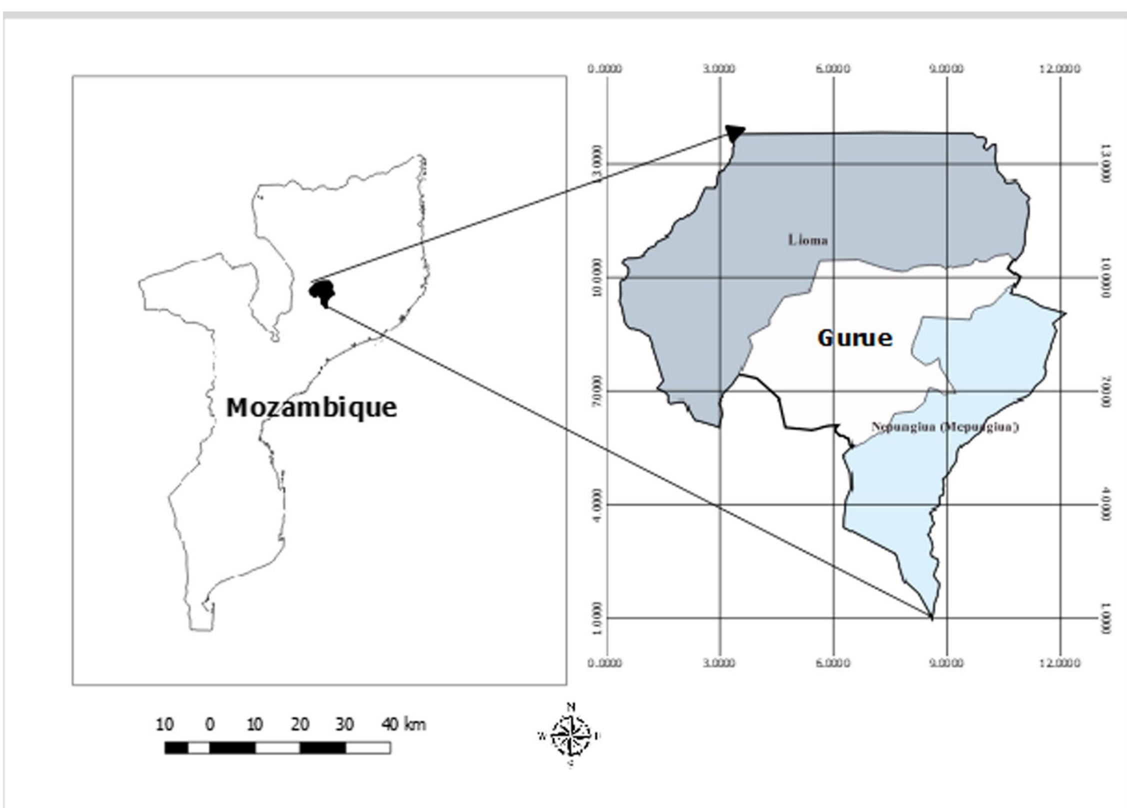

Fig. 1 Study area

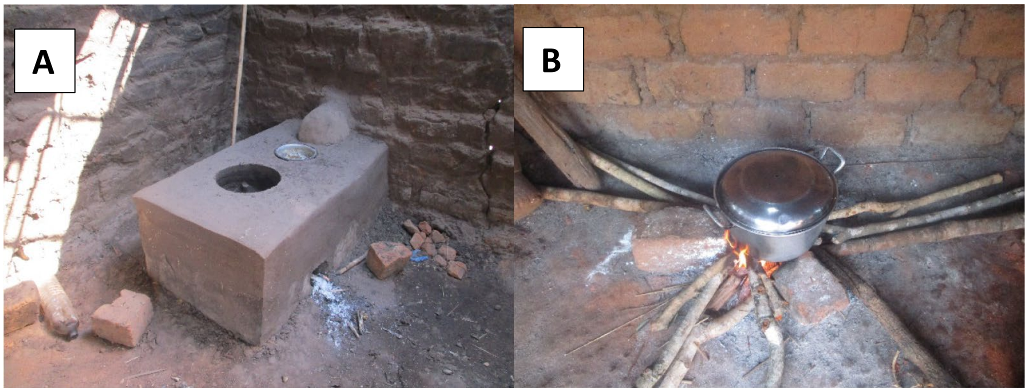

Fig. 2 **A** Improved biomass cook stoves; **B** three-stone stoves

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 (Δf) 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 (Δt) 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)

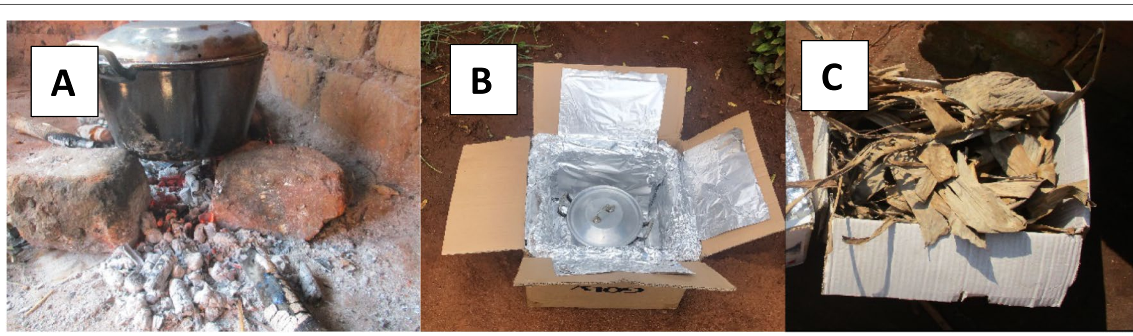

Fig. 3 Means of heat retention: **A** leftover charcoal; **B** heat retention box, **C** banana leaves

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

Type of food	Type of stove	Δt (min)	Δf (g)
Beans	ICS	77.50	7094.72
	TSF	89.72	8512.50
	Diff (TSF-ICS)	12.22[a] (14%)	1417.78[a] (17%)
Maize flour porridge	ICS	20.61	4978.28
	TSF	27.17	5448.89
	TSF-ICS	6.56[a] (24%)	470.61[a] (9%)

[a] Differences are significant at a level of significance of 0.05

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[a]	24.5	160[a]	24.5
HRB and TSF	175[a]	22.6	175[a]	12.2
BL and ICS	145[ab]	12.2	140[ab]	15.5
BL and TSF	150[ab]	19.0	145[ab]	12.2
LO and ICS	115[b]	12.2	105[b]	16.4
LO and TSF	135[b]	25.1	120[b]	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

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 (Δt). 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.

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 is 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

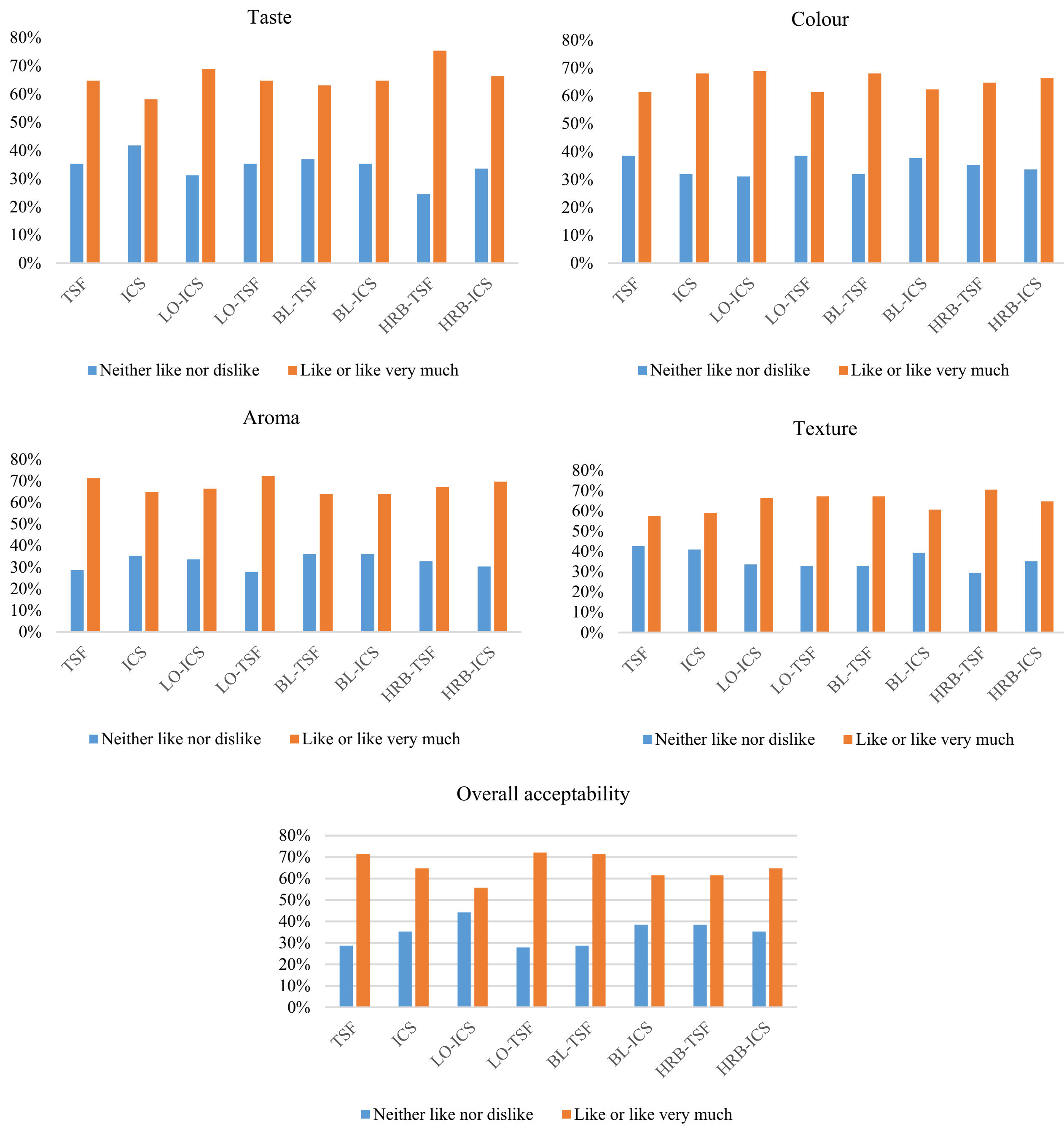

Fig. 4 Respondents preference for bean curry

TSF, 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.

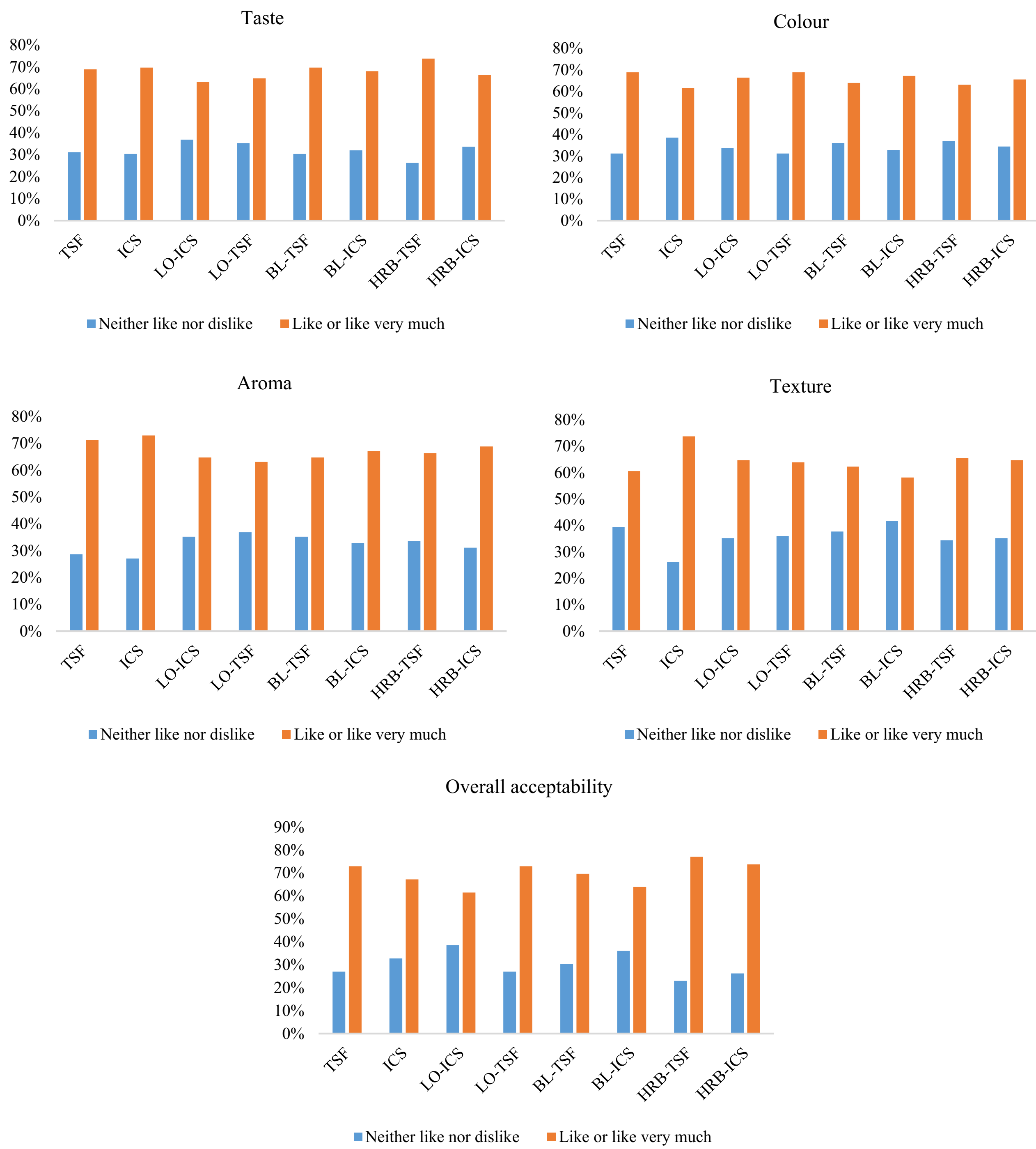

Fig. 5 Respondents preference for maize flour porridge

The average savings in cooking time were 6.6 min and 12.2 min (14% and 24%) for beans and maze 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 Taulo 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.

Acknowledgements
The project is financially supported by the Federal Ministry of Food and Agriculture (BMEL) based on the decision of the Parliament of the Federal Republic of Germany and managed by the Federal Office for Agriculture and Food (BLE). Sincere thanks to the Leibniz Centre for Agricultural Landscape Research (ZALF) in Müncheberg, Germany, for their logistical support in conducting the research in Gurué district, central Mozambique.

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.

Funding
Open Access funding enabled and organized by Projekt DEAL. The project is financially supported by the Federal Ministry of Food and Agriculture (BMEL) based on the decision of the Parliament of the Federal Republic of Germany and managed by the Federal Office for Agriculture and Food (BLE).

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.

Author details
[1]Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, 15374 Müncheberg, Germany. [2]Department of Agricultural Economics, Faculty of Life Sciences Thaer-Institute, Humboldt-Universität Zu Berlin, Unter den Linden 6, 10099 Berlin, Germany. [3]Department of Environment and Nature Conservation, Faculty of Agrarian Sciences, Universidade Lúrio, Unango Campus, Sanga, Niassa, Mozambique.

Received: 23 June 2021 Accepted: 12 June 2022
Published online: 21 June 2022

References

1. Nyambane A, Johnson FX, Romeu-Dalmau C et al (2020) Ethanol as a clean cooking alternative in Sub-Saharan Africa: insights from sugarcane production and ethanol adoption sites in Malawi and Mozambique. In: Gasparatos A, Naidoo M, Ahmed A, Karanja A, Fukushi K, Saito O, Takeuchi K (eds) Science for sustainable societies. sustainability challenges in sub-Saharan Africa II. Springer, Singapore, pp 115–144
2. IEA (2017) Energy access outlook 2017. International Energy Agency, Paris
3. Chidumayo EN, Gumbo DJ (2013) The environmental impacts of charcoal production in tropical ecosystems of the world: a synthesis. Energy Sustain Dev 17:86–94
4. Chirwa PW, Adeyemi O (2019) Deforestation in Africa: implications on food and nutritional security. In: Leal Filho W, Azul AM, Brandli L, Özuyar PG, Wall T (eds) Zero hunger. Springer International Publishing, Cham, pp 1–15
5. Pope DP, Mishra V, Thompson L et al (2010) Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. Epidemiol Rev 32:70–81
6. Smith KR (2006) Health impacts of household fuelwood use in developing countries. Unasylva 57:41–44
7. Thakur M, Nuyts PAW, Boudewijns EA et al (2018) Impact of improved cookstoves on women's and child health in low and middle income countries: a systematic review and meta-analysis. Thorax 73:1026
8. Zorrilla-Miras P, Mahamane M, Metzger MJ et al (2018) Environmental conservation and social benefits of charcoal production in Mozambique. Ecol Econ 144:100–111
9. Fisher S, Bellinger DC, Cropper ML et al (2021) Air pollution and development in Africa: impacts on health, the economy, and human capital. Lancet Planet Health 5:e681–e688
10. IHME (2022) GBD Compare. Institute for Health Metrics and Evaluation, Seattle. https://vizhub.healthdata.org/gbd-compare/. Accessed 19 May 2022
11. Farioli F, Dafrallah T (2012) Gender issues of biomass production and use in Africa. In: Janssen R, Rutz D (eds) Bioenergy for sustainable development in Africa. Springer, Netherlands, Dordrecht, pp 345–361
12. Adkins E, Oppelstrup K, Modi V (2012) Rural household energy consumption in the millennium villages in sub-Saharan Africa. Energy Sustain Dev 16:249–259
13. Hoffmann HK (2016) Bioenergy, development and food security in Sub-Saharan Africa. Humboldt-Universität zu Berlin, Lebenswissenschaftliche Fakultät, Berlin
14. Matinga MN, Annegarn HJ, Clancy JS (2013) Healthcare provider views on the health effects of biomass fuel collection and use in rural Eastern Cape, South Africa: an ethnographic study. Soc Sci Med 97:192–200
15. Kuusela O-P, Bowman MS, Amacher GS et al (2020) Does infrastructure and resource access matter for technical efficiency? An empirical analysis of fishing and fuelwood collection in Mozambique. Environ Dev Sustain 22:1811–1837
16. Sedano F, Silva JA, Machoco R et al (2016) The impact of charcoal production on forest degradation: a case study in Tete, Mozambique. Environ Res Lett 11:094020
17. Specht MJ, Pinto SRR, Albuquerque UP et al (2015) Burning biodiversity: fuelwood harvesting causes forest degradation in human-dominated tropical landscapes. Glob Ecol Conserv 3:200–209
18. Cuvilas CA, Jirjis R, Lucas C (2010) Energy situation in Mozambique: a review. Renew Sustain Energy Rev 14:2139–2146
19. Clough L (2012) The improved cookstove sector in East Africa: experience from the developing energy enterprise programme (DEEP). GVEP-Global Village Energy Partnership International, London
20. Honkalaskar VH, Bhandarkar UV, Sohoni M (2013) Development of a fuel efficient cookstove through a participatory bottom-up approach. Energy Sustain Soc 3:16
21. Sedighi M, Salarian H (2017) A comprehensive review of technical aspects of biomass cookstoves. Renew Sustain Energy Rev 70:656–665
22. Jagger P, Pedit J, Bittner A et al (2017) Fuel efficiency and air pollutant concentrations of wood-burning improved cookstoves in Malawi: implications for scaling-up cookstove programs. Energy Sustain Dev 41:112–120
23. Bardouille P (2012) From gap to opportunity: business models for scaling up energy access. Washington, DC
24. Fullerton DG, Bruce N, Gordon SB (2008) Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Trans R Soc Trop Med Hyg 102:843–851
25. van Gemert F, de Jong C, Kirenga B et al (2019) Effects and acceptability of implementing improved cookstoves and heaters to reduce household air pollution: a FRESH AIR study. NPJ Prim Care Respir Med 29:32

26. O'Shaughnessy SM, Deasy MJ, Doyle JV et al (2014) Field trial testing of an electricity-producing portable biomass cooking stove in rural Malawi. Energy Sustain Dev 20:1–10
27. Urmee T, Gyamfi S (2014) A review of improved Cookstove technologies and programs. Renew Sustain Energy Rev 33:625–635
28. Burwen J, Levine DI (2012) A rapid assessment randomized-controlled trial of improved cookstoves in rural Ghana. Energy Sustain Dev 16:328–338
29. Bensch G, Peters J (2013) Alleviating deforestation pressures? Impacts of improved stove dissemination on charcoal consumption in urban Senegal. Land Econ 89:676–698
30. Pailman W, de Groot J, Clifford M et al (2018) Experiences with improved cookstoves in Southern Africa. J Energy S Afr 29:13–26
31. Arora P, Das P, Jain S et al (2014) A laboratory based comparative study of Indian biomass cookstove testing protocol and Water Boiling Test. Energy Sustain Dev 21:81–88
32. Adkins E, Tyler E, Wang J et al (2010) Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. Energy Sustain Dev 14:172–185
33. L'Orange C, DeFoort M, Willson B (2012) Influence of testing parameters on biomass stove performance and development of an improved testing protocol. Energy Sustain Dev 16:3–12
34. Gebreegziabher Z, Beyene AD, Bluffstone R et al (2018) Fuel savings, cooking time and user satisfaction with improved biomass cookstoves: evidence from controlled cooking tests in Ethiopia. Resour Energy Econ 52:173–185
35. Abeliotis K, Pakula C (2013) Reducing health impacts of biomass burning for cooking—the need for cookstove performance testing. Energy Effic 6:585–594
36. Shankar AV, Quinn AK, Dickinson KL et al (2020) Everybody stacks: lessons from household energy case studies to inform design principles for clean energy transitions. Energy Policy 141:111468
37. Baldwin DE (2012) Sous vide cooking: a review. Int J Gastron Food Sci 1:15–30
38. Aworh OC (2021) Food safety issues in fresh produce supply chain with particular reference to sub-Saharan Africa. Food Control 123:107737
39. Woldt M, Moy G (2015) Literature review on effective food hygiene interventions for households in developing countries. FHI 360/FANTA, Washington, DC
40. Paparella A (2020) Food safety: definitions and aspects. In: Al-Rub FA, Shibhab P, Al-Rub SA, Pittia P, Paparella A (eds) Food safety hazards. GAVIN eBooks, Lisle, pp 1–4
41. Grace D, Alonso S, Mutua F, et al (2018) Food safety investment expert advice: Burkina Faso, Ethiopia, Nigeria. International Livestock Research Institute, Nairobi
42. Linscott AJ (2011) Food-borne illnesses. Clin Microbiol Newsl 33:41–45
43. Ricci A, Martelli F, Razzano R et al (2020) Service temperature preservation approach for food safety: microbiological evaluation of ready meals. Food Control 115:107297
44. U.S.FDA (2017) Food Code. U.S. Department of Health and Human Services, Washington, DC
45. Castán Broto V, Baptista I, Kirshner J et al (2018) Energy justice and sustainability transitions in Mozambique. Appl Energy 228:645–655
46. Taulo S, Wetlesen A, Abrahamsen R et al (2008) Microbiological hazard identification and exposure assessment of food prepared and served in rural households of Lungwena, Malawi. Int J Food Microbiol 125:111–116
47. Abedin HA, Rosen AM (2011) A critical review of thermochemical energy storage systems. Open Renew Energy J 4:42–46
48. Nienhuys S (2012) How to make a heat retention box (HRB). HUYS ADVIES
49. Bailey J, Esteves Miramont A, Quiroga VN et al (2019) Efficient cooking for mountainous areas: development, assembly and thermal behavior of cylindrical heat retention box. Sci Technol 9:12–17
50. Krishnan J, Gowtham M, Rahul K et al (2018) An organic composite phase change material for hot food storage: a review. Int J Mech Prod Eng Res Dev 8:457–470
51. Memon SA, Jaiswal MS, Jain Y et al (2020) A comprehensive review and a systematic approach to enhance the performance of improved cookstove (ICS). J Therm Anal Calorim. https://doi.org/10.1007/s10973-020-09736-2
52. Suresh R, Singh V, Malik J et al (2016) Evaluation of the performance of improved biomass cooking stoves with different solid biomass fuel types. Biomass Bioenergy 95:27–34
53. Mehetre SA, Panwar N, Sharma D et al (2017) Improved biomass cookstoves for sustainable development: a review. Renew Sustain Energy Rev 73:672–687
54. MacCarty N, Still D, Ogle D (2010) Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. Energy Sustain Dev 14:161–171
55. Tiffany HT, Chu (2013) The hot lunch dilemma: evaluating heat retention ability of insulated container with macaroni and cheese. British Columbia Institute of Technology
56. Kaushik V (2010) Designing fireless cooker of indigenous insulation material for better heat retention. J Hum Ecol 30:99–104
57. Estrada AV, Santos AJM (2019) Using diatomite to enhance the thermal storage of lunchbox. Paper presented at 2019 IEEE Integrated STEM Education Conference (ISEC), IEEE, Princeton, 16–16 March 2019
58. Leng G, Adan RA, Belot M et al (2017) The determinants of food choice. Proc Nutr Soc 76:316–327
59. Khandelwal M, Hill ME, Greenough P et al (2017) Why have improved Cook-Stove initiatives in India failed? World Dev 92:13–27
60. Malakar Y, Greig C, van de Fliert E (2018) Resistance in rejecting solid fuels: beyond availability and adoption in the structural dominations of cooking practices in rural India. Energy Res Soc Sci 46:225–235
61. Wang Y, Bailis R (2015) The revolution from the kitchen: social processes of the removal of traditional cookstoves in Himachal Pradesh, India. Energy Sustain Dev 27:127–136
62. Alfredo C (2016) Controlo pós-terapêutico da schistosomose e das parasitoses intestinais e atualização da situação malacológica nos distritos de Quelimane e Gurué, na província da Zambézia-Moçambique, Instituto de Higiene e Medicina Tropical
63. INE (2018) Folheto estatistico distrital gurue 2018. Instituto Nacional de Estatística, Quelimane
64. Barnes DF, Openshaw K, Smith KR et al (1993) The design and diffusion of improved cooking stoves. World Bank Res Obs 8:119–141
65. Uckert G, Hafner J, Graef F et al (2017) Farmer innovation driven by needs and understanding: building the capacities of farmer groups for improved cooking stove construction and continued adaptation. Environ Res Lett 12:125001
66. Bailis R, Ogle D, MacCarty N (2004) Controlled cooking test (CCT). Household Energy and Health Programme, Shell Foundation
67. Hafner J, Uckert G, Graef F et al (2018) A quantitative performance assessment of improved cooking stoves and traditional three-stone-fire stoves using a two-pot test design in Chamwino, Dodoma, Tanzania. Environ Res Lett 13:025002
68. Lee S, Lee DK (2018) What is the proper way to apply the multiple comparison test? Korean J Anesthesiol 71:353–360
69. Tomlins K, Ndunguru G, Stambul K et al (2007) Sensory evaluation and consumer acceptability of pale-fleshed and orange-fleshed sweet potato by school children and mothers with preschool children. J Sci Food Agric 87:2436–2446
70. Tomlins KI, Manful JT, Larwer P et al (2005) Urban consumer preferences and sensory evaluation of locally produced and imported rice in West Africa. Food Qual Prefer 16:79–89
71. Boutrolle I, Delarue J, Arranz D et al (2007) Central location test vs. home use test: contrasting results depending on product type. Food Qual Prefer 18:490–499
72. Oyeyinka AT, Pillay K, Siwela M (2017) Consumer awareness and acceptability of bambara groundnut as a protein source for use in complementary foods in rural KwaZulu-Natal. S Afr J Clin Nutr 30:87–92
73. Robinson J, Ibraimo M, Pemberton-Pigott C (2011) The uncontrolled cooking test: measuring three-stone fire performance in northern Mozambique. Paper presented at the DUE (Domestic Use of Energy) Conference, Cape Peninsula University of Technology, Cape Town, 11–13 April 2011
74. Jetter JJ, Kariher P (2009) Solid-fuel household cook stoves: characterization of performance and emissions. Biomass Bioenergy 33:294–305
75. Negash D, Abegaz A, Smith JU (2021) Environmental and financial benefits of improved cookstove technologies in the central highlands of Ethiopia. Biomass Bioenergy 150:106089

76. Massuque J, De Assis MR, Trugilho PF (2020) Characterization of Miombo species used by rural communities as fuelwood in Northern Mozambique. Energy Sources A Recov Util Environ. https://doi.org/10.1080/15567036.2020.1815910
77. Lee CM, Chandler C, Lazarus M, et al (2013) Assessing the Climate Impacts of Cookstove Projects: issues in Emissions Accounting. carbon market; carbon accounting; household energy. Stockholm Environment Institute, Stockholm
78. Ramos DC, Carneiro ACO, Tangstad M et al (2019) Quality of wood and charcoal from eucalyptus clones for metallurgical use. Floresta Ambiente. https://doi.org/10.1590/2179-8087.043518
79. Massuque J, De Assis MR, Loureiro BA et al (2021) Influence of lignin on wood carbonization and charcoal properties of Miombo woodland native species. Eur J Wood Wood Prod. https://doi.org/10.1007/s00107-021-01669-3
80. Hafner JM, Uckert G, Hoffmann HK et al (2020) Efficiency of three-stone fire and improved cooking stoves using on-farm and off-farm fuels in semi-arid Tanzania. Energy Sustain Dev 59:199–207
81. Sharma D, Jain S (2019) Impact of intervention of biomass cookstove technologies and kitchen characteristics on indoor air quality and human exposure in rural settings of India. Environ Int 123:240–255
82. de la Sota C, Lumbreras J, Pérez N et al (2018) Indoor air pollution from biomass cookstoves in rural Senegal. Energy Sustain Dev 43:224–234
83. Abdullahi G, Muhamad R, Dzolkhifli O et al (2017) Disinfestation of cocoa beans infested with life stages of Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) using solar heat trapped in a cardboard solar heater box. J Entomol Zool Stud 5:226–233
84. Wanjala W, Onyango A, Makayoto M et al (2016) Indigenous technical knowledge and formulations of thick (ugali) and thin (uji) porridges consumed in Kenya. Afr J Food Sci 10:385–396
85. Martins Y, Pliner P (2006) "Ugh! That's disgusting!": Identification of the characteristics of foods underlying rejections based on disgust. Appetite 46:75–85
86. Dovey TM, Aldridge VK, Dignan W et al (2012) Developmental differences in sensory decision making involved in deciding to try a novel fruit. Br J Health Psychol 17:258–272
87. Foster AD, Rosenzweig MR (2010) Microeconomics of technology adoption. Annu Rev Econ 2:395–424
88. Wądołowska L, Babicz-Zielińska E, Czarnocińska J (2008) Food choice models and their relation with food preferences and eating frequency in the Polish population: POFPRES study. Food Policy 33:122–134
89. Furst T, Connors M, Bisogni CA et al (1996) Food choice: a conceptual model of the process. Appetite 26:247–266
90. Chyung SY, Roberts K, Swanson I et al (2017) Evidence-based survey design: the use of a midpoint on the likert scale. Perform Improv 56:15–23
91. Raaijmakers QAW (2000) Adolescents' midpoint responses on Likert-type scale items: neutral or missing values? Int J Public Opin Res 12:209–217
92. Kulas JT, Stachowski AA (2013) Respondent rationale for neither agreeing nor disagreeing: person and item contributors to middle category endorsement intent on Likert personality indicators. J Res Pers 47:254–262
93. Kulas JT, Stachowski AA, Haynes BA (2008) Middle Response functioning in likert-responses to personality items. J Bus Psychol 22:251–259
94. Leung S-O (2011) A comparison of psychometric properties and normality in 4-, 5-, 6-, and 11-point likert scales. J Soc Serv Res 37:412–421
95. Adelson JL, McCoach DB (2010) Measuring the mathematical attitudes of elementary students: the effects of a 4-point or 5-point Likert-type scale. Educ Psychol Meas 70:796–807

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.