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Commonly Used Cooking Fuels and Their Impact on Nutritional and Sensorial Qualities of Food

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Abstract

Prior to consumption, most food commodities are cooked to enhance their nutritional, sensory, and safety attributes. Since the discovery of fire, cooking methods have evolved alongside urbanization and the population growth. The energy ladder theory outlines this progression, starting with traditional biomass, followed by petroleum-based products like kerosene and LPG, and eventually the introduction of electricity. Additionally, solar energy has emerged as an alternative cooking source. This paper reviews recent trends in household cooking energy sources, appliances, and their comparative efficiencies, with a focus on how these energy sources impact the nutritional and sensory qualities of food. Cleaner cooking fuels, such as LPG and electricity, have become increasingly popular due to their lower emissions, higher efficiency, and greater convenience. However, biomass, particularly firewood, remains the dominant energy source in low and middle-income countries. Despite the growing use of cleaner energy sources, the effects of various energy sources on the nutritional and sensory properties of food are still insufficiently studied. To compile the information presented in this review, peer-reviewed articles and relevant literature were selected based on their focus on the effects of different cooking energy sources, such as firewood, kerosene, LPG, and electricity, on food properties. Priority was given to empirical research providing comparative analyses. The findings indicate that modern energy sources, such as electricity, result in higher nutrient retention and better preservation of sensory qualities compared to traditional energy sources like firewood. Further studies are recommended to deepen our understanding of how these energy sources influence the nutritional and sensory characteristics of food, particularly in diverse cultural and economic contexts.

Keywords: cooking energy source, energy transfer, nutritional properties, sensory properties

1 Introduction

Cooking involves the application of heat to prepare food for consumption. According to the historical evidence, cooking may have started about 2 million years ago when man discovered and learned to control fire. Cooking is believed to have originated accidentally. However, more preferable taste, flavour and aroma of cooked food may have led early humans to repeat cooking, and after thousands of years, it has become a widespread practice (Smithers, 2018).

Cooking alters the composition of fresh food, modifies its biological, physical and chemical properties, beneficially affecting food's values by enhancing its nutritional and sensorial qualities as well as its texture, making it more palatable and attractive to consumers (Hager & Morawicki, 2013; Lee et al., 2017). Cooking also contributes to improving the safety of food by destroying pathogenic microorganisms and the formation or release of natural phytochemicals with functional and bioactive properties such as antioxidant or antimicrobial properties (Suleman et al., 2020). Furthermore, cooking may inactivate anti-nutritional factors (such as trypsin inhibitor, tannins and phytic acid) and enhance the digestibility of food and the bioavailability of nutrients (Hefnawy, 2011; Tian et al., 2016). However, cooking also results in some adverse effects including loss of various nutrients, formation of undesired or toxic compounds as well as compounds that negatively impact flavour perception, texture, or colour of the cooked food (Boekel et al., 2010; Tyagi et al., 2015). With the discovery of many energy resources, humans learned and explored various cooking techniques to prepare their foods and due to the levels of urbanization and living standards, people preferred more convenient and efficient cooking techniques like LPG and electricity as they moved up the energy ladder (Maes & Verbist, 2012; Nandasena et al., 2012; Pohekar et al., 2005). Each cooking fuel interacts differently with food, influencing its quality through variations in heat intensity, uniformity, and the cooking environment. These differences affect heat transfer mechanisms, which in turn impact the retention of essential nutrients and the development of sensory attributes such as flavor, texture, and aroma. Furthermore, health hazards associated with cooking fuels, mainly due to indoor air pollution, have severely contributed to switching into cleaner cooking fuels (Maes & Verbist, 2012; Wickramasinghe, 2011).

This review is focused on commonly used cooking energy sources around the world and their efficiencies and effect on the nutritional characteristics and sensorial qualities of cooked food. Moreover, the energy transfer process in cooking and energy efficiencies related to energy sources are extensively discussed. To compile the information presented in this review, we conducted a comprehensive search of peer-reviewed articles and relevant literature that examine the effects of different cooking energy sources on food properties. Studies were selected based on their relevance, particularly those that evaluated the nutritional and sensory attributes of food processed using varied energy sources such as firewood, kerosene, LPG, and microwaves. Priority was given to empirical research that provided comparative analyses, ensuring a well-rounded synthesis of findings. The literature search was carried out primarily via Google Scholar, chosen for its broad coverage and accessibility. Search terms were constructed using combinations of relevant keywords, including:

"Cooking energy sources and food nutrition"

"Effect of cooking on nutrient retention"

"Cooking fuel types and sensory characteristics of food"

"Cooking energy and food quality"

Boolean operators such as AND and OR were used to refine and limit the search, while filters were applied to include only articles published in English within the last 10 years, where possible. Articles were selected based on their relevance to the research focus—specifically, studies comparing the effects of different cooking energy sources on the nutritional composition and sensory properties of food commodities.

Despite this extensive search process, several limitations were encountered. Firstly, there was a limited number of studies that directly compared the effects of multiple cooking energy sources on both nutrient quality and sensory attributes. Secondly, in some of the available studies, the statistical significance of the results was either not clearly presented or entirely absent, reducing the strength and reliability of the evidence. Thirdly, methodological differences among studies—such as variations in food types, cooking times, and evaluation criteria—limited the feasibility of direct comparisons. Lastly, access limitations to certain subscription-based databases (e.g., Web of Science or Scopus) may have further restricted the inclusion of more comprehensive or high-impact studies.

In light of these constraints, the literature included in this review was selected based on its relevance, accessibility, and the overall quality of information in relation to the core theme.

2 Cooking energy sources

Depending on the availability of energy source, the energy efficiency of the fuels, choice of cooking utensils, personal preferences of the household members, cooking practices and cultural beliefs; many food preparation techniques are used by people all over the world (Akpalu et al., 2011; Elledge et al., 2012). Apart from that, other factors such as household income, cost of energy as well as the level of education are vital in employing a certain energy source for cooking (Damayanthi, 2018; Rahut et al., 2017, 2019; Ravindra et al., 2019). Widely used energy sources include biomass such as firewood, petroleum-based products (such as liquified petroleum gas (LPG), electricity and solar energy. This chapter aims to explain the characteristics of common energy sources used for cooking activities around the world, while describing factors related to its current popularity, advantages and limitations. Equipment used for heat transfer is also described.

2.1 Biomass

Biomass includes organic plant or animal materials which are commonly used as a solid fuel to produce energy. Over three billion people use biomass as their primary energy source worldwide (Nandasena et al., 2012; Singh & Heldman, 2014; Vakalopoulos et al., 2021). Biomass consumption is relatively higher in developing countries across sub-

Saharan Africa, Asia and Latin America (Ravindra et al., 2019).

In sub-Saharan Africa, about 90% of the population uses firewood as their domestic energy source (Njenga et al., 2019). Akpalu et al. (2011) reported the estimated firewood consumption in the rural areas in Ghana is 70%. In Kenya and Ethiopia, firewood consumption was reported as 90% of the rural population (Njenga et al., 2019). Higher firewood consumption in rural areas is a similar trend observed in many Asian countries as well. In India, 77.5% of the rural population relies on firewood for their household cooking purposes (Ravindra et al., 2019). In Nepal, 69% of the population uses solid biomass for cooking (Paudel et al., 2020). As (Thu et al., 2020) reported, approximately two-thirds of the rural population in Myanmar relies on firewood for their household cooking purposes. In Sri Lanka, biomass is the major source of energy used for cooking in the domestic sector accounting for nearly 69% of households nationwide (Musafer, 2020; Wickramasinghe, 2011).

Firewood is more preferred in rural areas, mainly because of its high availability as it can be easily found from farms or forests, dead wood from non-forest sources at low-cost or free of cost (Iiyama et al., 2014; Pohekar et al., 2005).

In addition to firewood, animal-based biomass including animal dung and waste from animal husbandry is being used as a cooking fuel, mainly in rural areas of developing countries such as India, Pakistan and sub-Saharan Africa (Bai et al., 2021; Mirza et al., 2008; Ravindranath et al., 2005). In the Tibetan region, the majority of the households utilize dried yak dung as a fuel source for cooking purposes (Bai et al., 2021). Dried animal-based biomass contains almost the same energy value as firewood. However, the heat transfer efficiency is only about 10% (Mirza et al., 2008).

Biomass is the most widely used energy source up to now. Despite the popularity, limitations such as time consumption, unavailability of biomasses due to deforestation and urbanization and possible health hazards have resulted in households evolving to alternative energy sources, especially in urban and suburban areas (Nandasena et al., 2012; Perera & Sugathapala, 2002; Wijayatunga & Attalage, 2002). According to WHO 2016, traditional cooking practices (TCP), which commonly use solid fuels like firewood, charcoal, or animal dung, produce indoor air pollution that is responsible for approximately 4.3 million deaths worldwide each year. Nevertheless, in many developing countries, the high costs of modern cooking energy sources are considered a major constraint to move to non-biomass energy sources (Martínez-gómez et al., 2016).

2.2 Petroleum-based products

Petroleum is a natural resource formed due to the decomposition of organic matter over millions of years (Schenk et al., 1997). Among all other household and industrial applications, petroleum-based energy sources are very popular as energy sources for cooking applications. The most commonly used petroleum-based products used for household cooking are kerosene, LPG and liquefied natural gas (LNG).

Kerosene is a mixture of hydrocarbon chains with 6 to 16 carbon atoms, derived from the distillation of crude oil (Lam et al., 2012). Kerosene stoves are more energy-efficient, easily controllable and convenient compared to biomass stoves (Pohekar et al., 2005). Prior to the introduction and widespread use of LPG cooking, kerosene burners were commonly used as household cooking devices in Africa, Asia and Latin America (Lam et al., 2012; Perera & Sugathapala, 2002). As an example, (Paudel et al., 2020) reported that kerosene was commonly used as a cooking fuel in 34% of households in urban areas in Nepal, in 2001, while the LPG usage was only 27%. In 2013, 26% of the population in Nigeria were reported using kerosene for cooking, comprising 48% and 9% of urban and rural households respectively (Ozoh et al., 2018). According to (Thoday et al., 2018) kerosene was the primary cooking fuel for 37% of households in Indonesia in 2007.

However, the usage of kerosene has decreased in recent years probably due to the unpleasant smell given off by kerosene burnt in stoves, safety issues and health hazards associated with the emissions compared to clean cooking fuels (Akpalu et al., 2011; Paudel et al., 2020; Pohekar et al., 2005).

LPG is produced as a byproduct in petroleum refining and contains propane, butane, or a combination of the two (Adamu et al., 2020; Thoday et al., 2018). Compared to biomass and kerosene, the introduction of LPG was promising in terms of convenience and time saving (Akpalu et al., 2011; Paudel et al., 2020; Thoday et al., 2018).

People are switching to LPG from kerosene and biomass significantly, especially in Asian countries, due to its superiority over biomass (Wright et al., 2020). As (Thoday et al., 2018) reported, a mega conversion program from kerosene to LPG took place in Indonesia between 2007 and 2012, which resulted in approximately two-thirds of all households switching to LPG. A national transition from cooking with biomass and kerosene to cooking with LPG was facilitated in Ecuador, since the 1970s, and as of 2014, more than 90% of households were reported to use LPG as their primary cooking fuel (Gould et al., 2020). According to the survey data of the Department of Census and Statistics, 29.3% of the total population in Sri Lanka used LPG as their major cooking energy by 2017 (Department of Census and Statistics, 2017).

However, previously LPG was commonly used in households with middle and high income in urban areas as the distribution networks are poor in rural regions and high initial cost and increasing prices (Perera & Sugathapala, 2002; Pohekar et al., 2005). Safety concerns about leaks from old valves, faulty cylinders and possible explosions are considered barriers to LPG adoption in rural areas. Additionally, in colder climates, wood-burning stoves are valued for both cooking and heating, while cultural preferences for traditional food flavors further discourage exclusive LPG use. These barriers result in many households continuing to rely on multiple fuel types (Gould & Urpelainen, 2018).

2.3 Electricity

Electricity is a secondary fuel that is produced by transforming other energy sources such as hydropower, steam from heat generated either by a nuclear reaction or by burning fossil fuels (Adamu et al., 2020). According to International Energy Agency, (IEA, 2020) 89.95% of the world population has access to electricity and the number of people without access to electricity has dropped from almost 860 million in 2018 to 770 million in 2019. Out of the total proportion, 75% of the population without access to electricity live in sub-Saharan Africa. However, due to the COVID-19 pandemic, people without adequate access to electricity are set to increase in 2020, especially in sub-Saharan Africa. About 96% of the population in developing countries in Asia have access to electricity by 2019 (IEA, 2020).

Electricity is considered an ideal source of energy for cooking, as it producess no pollutant emissions, is convenient to handle, has high conversion efficiency and does not cause continuous deforestation (Bhandari, 2018; Pohekar et al., 2005). In industrialized countries, electricity is commonly used as household cooking energy (Wright et al., 2020). For example, in the United States, almost 63% of the population uses electricity as their primary energy source for cooking. Similarly, in Europe, the majority of cooking appliances are electric (Hager & Morawicki, 2013).

However, electricity is not widely used for cooking in low and middle-income countries as it is relatively expensive, requires a large amount of energy, high price of electrical cooking appliances and the households may not have a continuous supply of electricity (Kapsalyamova et al., 2021; Wright et al., 2020). It is the primary cooking medium for only 5% of urban households in low and middle-income regions in the world (Wright et al., 2020).

In areas where a sufficient electrical power supply is available, specialized electric appliances such as electric kettles, rice cookers, induction cookers, ovens and microwaves are being used for cooking purposes (Smith & Sagar, 2014).

Microwave cooking was first recognized in around 1940s and has become more popular as a household cooking technique especially in countries like United States, Canada and Europe (Orsat et al., 2017; Vaid, 2008). Along with the massive urbanization and accessibility to electricity, usage of microwave ovens has increased in developing countries as well. Microwave ovens are mainly used for heating and cooking food (Orsat et al., 2017). Microwave cooking has gained attention as it has reduced food preparation time (Gawat et al., 2024; Jouquand et al., 2015). According to (Bejerholm et al., 2014), when cooking meat in a microwave oven, total cooking time can be reduced by one-third to one-half compared to conventional cooking in an oven. Also, the energy consumption is low in microwaves and its ability to preserve the nutritional integrity of foods is important in food processing (Akkarachaneeyakorn, 2010; Jouquand et al., 2015). However, due to the non-uniform heating in microwave cooking, hot and cold spots form in the food, which could result in the survival of the foodborne microorganisms in the cold spots, raising food safety concerns (Jouquand et al., 2015; New et al., 2017; Vadivambal & Jayas, 2010).

2.4 Solar Energy

Lack of access to clean cooking fuels is a major constraint, especially in developing nations with relatively weak infrastructure. As a result, solar energy has emerged as a promising renewable and sustainable energy option for cooking purposes. Here, the energy of the sunlight is converted into heat energy and used for cooking activities. Solar energy is a freely available source in abundance, hence, this technique can be used in any location with sufficient solar radiation throughout the year (Aramesh et al., 2019).

The first scientific evidence of a solar cooker is believed to be in the 18th century, a black insulated solar cooker built by Nicholas de Saussure (Otte, 2014). Solar cooking has been subjected to many research studies over the years. Currently, there are a few common types of solar cookers available; such as box cooker, panel cooker and parabolic reflector cooker (Iessa et al., 2017). As reported by the Solar Cookers International Association, over 3.1 million solar cookers have been installed and are used by more than 11 million people around the globe and the majority are located in Africa and South Asia (Aramesh et al., 2019).

Despite the many advantages and potential sustainable development contributions, solar cooking has not achieved large-scale success in household cooking. The main reasons for this include, the lack of social acceptance and awareness, the requirement of the specific secondary cooking devices, lack of availability of such devices and their high prices, slower cooking rates and inability to use all the time (Aramesh et al., 2019; Iessa et al., 2017).

2.5 Biogas

Biogas is an eco-friendly and renewable energy source produced through the anaerobic digestion of organic materials like agricultural waste, animal manure, and food scraps (Yasmin & Grundmann, 2019). Biogas usually consists of CH_4, CO_2, and traces of other gases like H_2S and moisture (P. Singh & Kalamdhad, 2022). Biogas is considered one of the cleanest forms of cooking energy source and a promising alternative for the households with sufficient and suitable organic feedstock (Clemens et al., 2018; Lohani et al., 2021). In terms of efficient fuel use, total emissions, indoor emissions, and safety, biogas cookstoves show a significant performance (Lohani et al., 2021).

Globally, approximately 50 million biogas systems have been installed for cooking purposes, with the majority located in Asia, particularly in China and India (Clemens et al., 2018).

However, the rate of adoption of biogas as a cooking fuel is relatively low since the initial cost of constructing biogas plants and digesters is high, which can be prohibitive for low-income households (Clemens et al., 2018; Yasmin & Grundmann, 2019). Apart from that, the requirement for regular maintenance and technical expertise for efficient operation is a limiting factor which may cause failures in biogas production (Hewitt et al., 2022).

3 Cooking as an energy transfer process

In cooking, thermal energy transferred as heat from the energy source/spent fuel to the food material usually result in an increase in temperature. According to a temperature gradient, heat transfer is a dynamic process in which heat is moved spontaneously from one body to another body. Heat transfers to the food in three modes; conduction, convection and radiation (Fellows, 2009; Fryer & Robbins, 2005; McGee et al., 1999).

Heat is transferred from the energy source used for cooking such as burning firewood, LPG, kerosene or heated electric coil to the contact surface of the cooking pot through conduction and the food is subjected to an influx of heat as a result of physical contact with the hot surface of the pot (Karunanithy & Shafer, 2016).

Forced convention is used in conventional ovens, where a fan and an exhaust system are used to blow hot air over and around the food before venting it back out (Fellows, 2009; Singh & Heldman, 2014).

Infrared and microwave radiation are the commonly used radiant cooking methods (Singh & Heldman, 2014). Solar radiation is used for solar cooking systems. In direct-type solar cookers, heat is transferred directly by solar radiation and in indirect types, a heat transfer fluid is involved (Singh et al., 2021).

3.1 Heat profiles and efficiencies of cooking energy sources

The rate of heat transfer affects the energy consumption efficiency and the energy intensity (Anozie et al., 2007). Different fuel types are believed to have various efficiency values and the design of the cooking appliance is also a contributing factor (Anozie et al., 2007; Maccarty et al., 2010; Shaisundaram et al., 2021).

The most primitive type of cooking energy, biomass, (including firewood) results in low energy efficiency. In traditional biomass stoves, burning efficiency is very low while they release large amounts of harmful pollutants due to incomplete burning of the solid biomass fuel. Other than that, traditional stoves including three-stone firewood stoves consume large amounts of solid biomass due to their low burning efficiency (Suresh et al., 2016).

Apart from the fuel itself, the geometry of the stove and how closely the hot gases pass around the bottom and sides of the pot, greatly impact on heat transfer efficiency (Maccarty et al., 2010). The efficiency of traditional firewood stoves such as three-stone stoves is remarkably limited as the energy loss is high. However, due to the mass popularity of firewood as cooking energy, many projects were carried out designing novel biomass stoves increasing their efficiencies into higher levels (Kumar et al., 2013; Shaisundaram et al., 2019).

As energy sources became more advanced, the efficiencies have gradually increased in the fuels that are at higher levels of the energy ladder. LPG and kerosene have a comparatively higher energy density, high combustion efficiency, and high heat transfer efficiency (Akpalu et al., 2011). According to (Wijayatunga & Attalage, 2002), LPG stoves and kerosene stoves are considered to be four times and three times more efficient, respectively, than firewood stoves.

Being the highest level in the energy ladder model, electricity has greater efficiency in cooking in comparison with biomass, kerosene and LPG. As a result, electric cooking appliances have gained attention in modern households. In a scientific study evaluating the cooking energy costs and efficiencies, the air pollution impacts of cooking energy consumption and the effect of the energy policy in the cooking energy sector in Nigeria, a water boiling test was carried out using the common cooking energy sources; firewood, kerosene, LPG and electricity. In the study, energy consumption efficiencies and energy intensities were analyzed, and a similar trend was observed with efficiency values for boiling water of 25%, 46%, 73%, 79%, 66% and 90% for firewood, kerosene, gas, electric immersion coil, electric heating coil and electric hot plate, respectively indicating the remarkable energy efficiency shown by electrical cooking appliances. The efficiency values vary among those electric appliances depending on their design, even though the energy source is the same (Anozie et al., 2007).

(Chheti et al., 2017), analyzed the performance of LPG cook stove and induction cooktop used for cooking purposes in Bhutan and reported that the efficiency of the induction cooktop can be as high as 80-84% compared to electrical resistance-based cooktop which is 50-60%, whereas, efficiency value was only 40% with LPG cooktop. The main reasons for the recorded low-efficiency value for the LPG cooktop were considered due to conversion losses of LPG fuel to thermal energy, and energy losses from space between the pot and the cook stove (Chheti et al., 2017).

Analysis of LPG, electric and induction cookers during cooking typical Ecuadorian dishes have revealed that energy consumption of LPG stove is considerably greater with respect to induction stove. In addition, it has been observed that the cooking time was increased for the electric resistance stove compared to the electric cooker. The increment in time was described to be related to the low power of the electric cooker used for the study. In addition to that, relatively low energy consumption was recorded in the induction cooker with respect to the electric cooker. In fact, it was affirmed that the induction stove was more efficient than the electric and LPG stoves, as it reduced the cooking time and energy consumption (Martínez-gómez et al., 2016).

Akinoso and Oladeji, 2017 conducted a study that investigated the energy and time requirements for cooking pigeon pea (*Cajanus cajan*). In this study, the energy consumption and cooking times for kerosene, LPG, and electric stoves were recorded, as presented in Table 1.

4 Effect of the cooking energy sources on food materials

The energy sources used for cooking have varying energy efficiencies, heat profiles and energy transfer mechanisms as mentioned in section 3. Therefore, the heat transfer, cooking temperatures and time durations are different in each energy source. The characteristics in cooked food were highly influenced by these cooking parameters (Doležalová et al., 2023). Higher temperatures and longer cooking times can cause major alterations to the sensory attributes including colour, flavours, etc (Vadivambal & Jayas, 2010). Apart from that, nutrient composition of the foods can be significantly altered, changing their nutritional values either beneficially or negatively (Fabbri & Crosby, 2016). Hence, the quality of the final product is affected by the energy source used for cooking.

4.1 Effect on nutritional qualities

Primary cooking energy sources such as biomass have long cooking durations which may result in higher nutrient losses (Damayanthi, 2018). Energy sources, which are in the upper levels of the energy ladder, often give lower cooking times and higher temperatures due to their higher efficiency values. Electric cooking often results in lower cooking time and higher energy efficiencies and particularly, induction cook stoves have reduced cooking time durations resulting in more preferable final products (Martínez-gómez et al., 2016). In microwave cooking, shorter cooking times were reported compared to the traditional methods which transfer energy through conduction and convection apart from radiation (Gavahian et al., 2019). As a result, nutrient retention is said to be higher in microwave cooking compared to conventional cooking (Jouquand et al., 2015; Orsat et al., 2017).

4.1.1 Macronutrients

Thermal treatment while cooking leads proteins to denaturation and undergo irreversible changes in their three-dimensional structure. Starches in the food gelatinize during cooking in the presence of water. Moreover, due to temperature, unsaturated fatty acids and cholesterol are rapidly oxidized in the presence of oxygen and in the absence of food antioxidants and mono and polyunsaturated fatty acids can be isomerized. Maillard reactions can occur in amino acids and sugars causing noticeable changes including characteristic browning colour and complex flavours in food material (Rechkemmer, 2007).

Different cooking methods exhibit varying thermal efficiencies and heating properties, as highlighted in section 3.1. Consequently, the extent of nutrient changes fluctuates, significantly affecting the nutrient composition of the cooked product and higher temperatures can induce protein denaturation and lipid oxidation, while variations in moisture content and the final product's consistency may influence the quantifiable macronutrient content (Eze, 2016; Nunn et al., 2016). Several studies have been carried out by scientists to analyze the effect of cooking energy source on macronutrients of various food items, and they have been summarized in Table 1.

In a study conducted by Li et al., 2016 , the total lipids and free fatty acids contents of pork belly cuts which were pretreated and stewed using induction and LPG flame heating, were analyzed. The results indicated that the total lipid content in pork belly was reduced in samples stewed with LPG flame heating compared to those stewed with induction heating. Furthermore, LPG flame heating significantly reduced the total saturated fatty acid content ($p < 0.01$) compared to induction heating. The greater thermal transmission in flame heating during stewing, as opposed to induction heating, likely caused more saturated fatty acids to melt, resulting in lower levels in the final product (Li et al., 2016).

Eze, 2016 has compared the macronutrient content in beans, yams and rice samples cooked with firewood, LPG and biogas. According to the results, firewood, LPG and biogas cooking had varying effects on the macronutrients of the samples. No significant difference was observed in the macronutrient contents of beans cooked with all techniques. Also, the protein content in cooked yams showed no significant difference. In contrast, carbohydrate and fat contents were significantly different in samples. In cooked rice, carbohydrates and fat contents were significantly higher in LPG cooked samples compared to firewood and biogas cooked samples (Eze, 2016). These varying nutrient compositions may have resulted due to the differences in cooking time and heat intensities of firewood, LPG and biogas.

Similarly, Martínez-gómez et al., 2016, analyzed the macronutrient contents in typical Ecuadorian dishes heated and boiled in electric, induction and LPG stoves. There, carbohydrate, protein, and fat contents of heated milk, boiled chochos, hard-boiled egg, boiled broccoli and Russian salad with boiled carrots, potatoes and peas were analyzed. In addition to the boiled samples, they have analyzed the macronutrient contents of steamed fish and grilled chicken samples, which were processed using LPG and induction stoves. Mentioned macronutrient contents showed slight variations with different cooking energy sources; however, the significance of those readings is not reported.

Mensah et al., 2022 investigated the effects of microwave and conventional heating on the proximate composition of spiced millet porridge, specifically comparing the crude protein and crude fat contents of samples boiled using LPG and microwaves at power levels of 360, 600, and 800 W, respectively. The study revealed that porridge cooked with microwave heating consistently exhibited lower crude protein contents compared to LPG-cooked samples due to the higher temperatures generated by microwave cooking, which caused protein denaturation, reducing the quantifiable protein in the samples. In contrast, microwave-cooked samples exhibited higher crude fat content compared to conventionally cooked samples, with the fat content increasing as the microwave power was elevated. The authors attributed this trend to the higher temperatures generated during microwave cooking, which not only induced protein denaturation but also facilitated the thermal decomposition and breaking of bonds that bind fatty acids together. This process caused the fatty acids to detach and become more accessible, leading to an apparent increase in the fat content of the samples.

4.1.2 Micronutrients

Micronutrients such as vitamins and minerals are typically more sensitive to heat. As a result, cooking has an adverse effect on macronutrients content in food. Therefore, cooking time and efficiency are critical for micronutrients. Previous studies have reported that microwave cooking minimizes the losses of micronutrients and vitamins due to their reduced cooking times (Chin et al., 2022; S. Singh et al., 2015). According to Chin et al., 2020, microwave cooking yielded a higher total phenolic content (TPC) and antioxidant activities in Riceberry rice compared to conventional electric cooking. Also, as reported by Chin et al., 2022, microwave cooking has increased the antioxidant activity of Chinese kale.

Limited number of studies are available in investigating the effect of different cooking energy sources on micronutrients. Nunn et al., 2016, have analyzed the impact of conventional boiling, induction boiling and microwave steaming on the micronutrients of broccoli, carrots, green beans and sweet potatoes and identified that the $\beta-$carotene contents were affected by the cooking method. The key findings are summarized in Table 2.

Similarly, Eze, 2016, examined the effects of firewood, LPG and biogas cooking on beans, yams and rice. Substantial variations were discovered in the levels of calcium and phosphorus as shown in table 3.

4.2 Effect on sensorial quality

Food acceptance relies on sensory or organoleptic attributes, involving the evaluation of flavour, texture, taste, and aftertaste using human senses. It is a scientific method to measure, analyze, and interpret responses to products through sight, smell, touch, taste, and hearing (Ray, 2021). Food changes its colour, flavour, taste and texture during cooking. All the modifications induced by cooking impact on the sensory qualities of the cooked product (Buratti et al., 2020). Cooking energy sources such as firewood, LPG, electric stoves, induction, and microwave ovens can impact these sensory attributes significantly. The differences arise due to varying heat transfer methods, cooking temperatures, and time, which influence chemical reactions and physical transformations in food.

It is commonly believed that the smoky flavour and texture imparted by biomass cooking are irreplaceable. For example, cooking with firewood imparts a distinct smoky flavour to grilled foods due to the release of aromatic compounds during combustion (Husbands & Cranford, 2019). This flavour is often preferred in certain traditional dishes but may not be desirable for others. Recent studies suggest that preferences for these sensory attributes are influenced by individual tastes and cultural context. Traditional cooking methods are frequently associated with enhanced flavour due to their deep cultural significance (Leary et al., 2021). Conversely, some individuals, particularly those seeking a modern lifestyle, may prefer food without the smoky flavor typically linked to biomass cooking. While smoky flavours are preferred for specific dishes, evidence from studies in Kenya and blind taste tests in Myanmar indicates that food cooked with electricity was often rated as the most flavourful overall (Leary et al., 2019a; Leary et al., 2019b).

In a study carried out by Awolomate, 2022 the sensory attributes of Tilapia (Oreochromis niloticus) were evaluated by grilling the samples using three different cooking energy sources: charcoal, wood, and an electric grill. The findings indicated that Tilapia cooked with an electric grill was rated highest in appearance compared to those cooked with firewood and charcoal. However, in terms of sensory attributes such as taste, tenderness, texture, and salinity, the fish prepared with the electric grill was considered inferior. Among the other methods, firewood-heated Tilapia exhibited the best texture but was noted to have the least favorable flavor profile.

Particularly in the baking process, microwave baking and conventional baking were often compared by several researchers and it was revealed that the desired crust formation and brown colour formation was not possible in microwave baking (Chandrasekaran et al., 2013). Similarly, microwave cooking does not give the typical brown colouration in meat compared to the conventional methods. This is attributed to the notably short cooking time in microwave baking/cooking (Yarmand & Homayouni, 2011).

Several studies have highlighted the diverse impacts of different energy sources on the sensory properties of cooked food, as summarized in Table 4. As reported by Nunn et al., 2016, induction cooking is more preferred in terms of organoleptic properties compared to conventional boiling of broccoli, carrots and green beans. In the same context, Martínez-gómez et al., 2016, have further identified induction cooking is more acceptable for broccoli, orange with oatmeal and grilled chicken, compared to LPG cooking. Eze, 2016 has observed varying significant differences in the organoleptic properties of rice, beans and yam when cooked with firewood and LPG. Vaid, 2008 reported a non-significant difference in organoleptic properties between microwave and solar-cooked samples of groundnuts, sweet corn, rice and mung dal. In another study, Akinoso and Oladeji, 2017 have concluded that the method of cooking has no effect on the taste, colour and overall acceptability of pigeon pea.

Even though specific cooking energy sources were found to be more acceptable for particular foods in terms of sensory qualities, researches on this topic are still lacking.

5 Conclusion

Cooking plays an important role in domestic households. This review intends to identify and analyze various techniques used for household cooking purposes and how those cooking techniques affect the nutritional and sensory properties of food.

As elaborated in this review, commonly used cooking fuel sources include biomass, kerosene, LPG, electricity and solar power. Energy efficiencies of these fuel sources and associated cooking techniques are different; electricity bearing a higher efficiency compared to biomass, kerosene and LPG. Using electricity as an energy source, several cooking appliances such as microwave ovens, electric cookers and induction cookers have been introduced and gained attention in recent years as household cooking devices. Among them, induction cooker is considered the most energy-efficient technique.

Numerous discussions have explored the impact of various cooking energy sources on the nutritional quality and sensory properties of the final cooked product. This review highlights that the efficiency and effects on nutrient retention can vary significantly depending not only on the type of energy source but also on the specific cooking method employed. Studies indicate that modern energy sources, such as electricity used in induction cooking and microwave cooking, tend to result in higher nutrient retention compared to traditional energy sources like firewood.

In terms of sensory properties, traditional energy sources like firewood can impart distinctive flavors and aromas to food. While these properties are desirable in certain instances like grilling, they can be undesirable in some other contexts. In contrast, modern energy sources such as LPG, microwave, and induction cooking are less likely to significantly alter the sensory qualities of food. This makes them more suitable for preserving the original sensory attributes of food while ensuring consistency in taste and aroma. Therefore, these modern methods demonstrate higher energy efficiency, further supporting their use as optimal cooking solutions for maintaining both nutritional and sensory quality in food.

However, the available literature discussing these aspects is limited. Most of the previous studies have mainly focused on the surveillance of the current usage and health impacts of these cooking energy sources. Therefore, further studies are required to analyze the impact of these fuel sources and techniques on changes of nutritional and sensorial properties of cooked food items.

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Conflict of Interest

None.

References

Adamu, M., Adamu, H., Ade, S., & Akeh, G. (2020). Household energy consumption in nigeria: A review on the applicability of the energy ladder model. *Journal of applied sciences and environmental management*, *24*(2), 237–244.

Akinoso, R., & Oladeji, O. D. (2017). Determination of energy and time requirement for cooking pigeon pea (cajanus cajan). *Journal of Biosystems Engineering*, *42(1)*, 56–61.

Akkarachaneeyakorn, S. e. a. (2010). Optimization of combined microwave–hot air roasting of malt based on energy consumption and neo-formed contaminants content. *Journal of Food Science*, *75(4)*, E201–7. https://onlinelibrary.wiley.com/doi/full/10.1111/j.1750-3841.2010.01567.x

Akpalu, W., Dasmani, I., & Aglobitse, P. B. (2011). Demand for cooking fuels in a developing country: To what extent do taste and preferences matter? *Energy Policy*, *39*(10), 6525–6531.

Anozie, A. N., Bakare, A. R., Sonibare, J. A., & Oyebisi, T. O. (2007). Evaluation of cooking energy cost, efficiency, impact on air pollution and policy in nigeria. *Energy*, *32*(7), 1283–1290.

Aramesh, M., Ghalebani, M., Kasaeian, A., Zamani, H., Lorenzini, G., Mahian, O., & Wongwises, S. (2019). A review of recent advances in solar cooking technology. *Renewable Energy*, *140*, 419–435. https://doi.org/10.1016/j.renene.2019.03.021

Awolomate, S. e. a. (2022). Physical, chemical, and microbiological properties of tilapia fish as affected by charcoal, electric griller, and firewood heat sources. *Nigerian Journal of Agriculture and Agricultural Technology*, *2(2)*, 104–13. https://njaat.com.ng/index.php/njaat/article/view/291

Bai, Y., et al. (2021). Biochar from pyrolyzed tibetan yak dung as a novel additive in ensiling sweet sorghum: An alternate to the hazardous use of yak dung as a fuel in the home. *Journal of Hazardous Materials*, *403*, —.

Bejerholm, C., Tørngren, M., & Aaslyng, M. (2014). Cooking of meat. *Encyclopedia of Meat Sciences*, *1*, 370–76.

Bhandari, R. (2018). Electricity as a cooking means in nepal — a modelling tool approach. *Sustainability*, *10*, —.

Boekel, M. V., et al. (2010). A review on the beneficial aspects of food processing. *Molecular Nutrition & Food Research*, *54*, 1215–47.

Buratti, S., Cappa, C., Benedetti, S., & Giovanelli, G. (2020). Influence of cooking conditions on nutritional properties and sensory characteristics interpreted by e-senses: Case-study on selected vegetables. *Foods*, *9(5)*, —.

Chandrasekaran, S., Ramanathan, S., & Basak, T. (2013). Microwave food processing — a review. *Food Research International*, *52(1)*, 243–61. http://dx.doi.org/10.1016/j.foodres.2013.02.033

Chheti, R., Chhoedron, D., Sunwar, T., & Robinson, D. A. (2017). Analysis on integrated lpg cook stove and induction cooktop for cooking purposes in bhutan. *International Journal of Science and Research*.

Chin, L., Therdthai, N., & Ratphitagsanti, W. (2022). Effect of conventional and microwave cooking conditions on quality and antioxidant activity of chinese kale (brassica alboglabra). *Applied Food Research*, *2(1)*, 100079. https://doi.org/10.1016/j.afres.2022.100079

Chin, L., Therdthai, N., & Ratphitagsanti, W. (2020). Effect of microwave cooking on quality of riceberry rice (oryza sativa l.) *Journal of Food Quality*, *2020*.

Clemens, H., Bailis, R., Nyambane, A., & Ndung'u, V. (2018). Africa biogas partnership program: A review of clean cooking implementation through market development in east africa. *Energy for Sustainable Development*, *46*, 23–31.

Damayanthi, B. (2018). Socio-economic determinants of cooking fuel choice among households in rural sri lanka. *Journal of Environment and Earth Science*, *8(9)*, 115–26.

Department of Census and Statistics. (2017). Sri lanka demographic and health survey 2016.

Doležalová, J., et al. (2023). Effect of various cooking methods on cooking loss, sensory and instrumental properties of pork neck. *International Journal of Gastronomy and Food Science*, *32*, 100737.

Elledge, M. F., et al. (2012). A profile of biomass stove use in sri lanka. *International Journal of Environmental Research and Public Health*, *9(4)*, 1097–1110.

Eze, J. I. (2016). Nutritional and organoleptic properties of three common nigerian foods cooked with three different energy sources. *Scientific Research and Essays*, *7(22)*, 2010–16.

Fabbri, A. D., & Crosby, G. A. (2016). A review of the impact of preparation and cooking on the nutritional quality of vegetables and legumes. *International Journal of Gastronomy and Food Science*, *3*, 2–11. http://dx.doi.org/10.1016/j.ijgfs.2015.11.001

Fellows, P. J. (2009). Heat processing. In *Food processing technology* (pp. 339–66).

Fryer, P. J., & Robbins, P. T. (2005). Heat transfer in food processing: Ensuring product quality and safety. *Applied Thermal Engineering*, *25*, 2499–2510.

Gavahian, M., Chu, Y., & Farahnaky, A. (2019). Effects of ohmic and microwave cooking on textural softening and physical properties of rice. *Journal of Food Engineering*, *243*, 114–24. https://doi.org/10.1016/j.jfoodeng.2018.09.010

Gawat, M., et al. (2024). Effects of microwave processing in comparison to sous vide cooking on meat quality, protein structural changes, and in vitro digestibility. *Food Chemistry*, *434*, 137442. https://doi.org/10.1016/j.foodchem.2023.137442

Gould, C. F., et al. (2020). Household fuel mixes in peri-urban and rural ecuador: Explaining the context of lpg, patterns of continued firewood use, and the challenges of induction cooking. *Energy Policy*, *136*, 111053. https://doi.org/10.1016/j.enpol.2019.111053

Gould, C. F., & Urpelainen, J. (2018). Lpg as a clean cooking fuel: Adoption, use, and impact in rural india. *Energy Policy*, *122*, 395–408. https://doi.org/10.1016/j.enpol.2018.07.042

Hager, T. J., & Morawicki, R. (2013). Energy consumption during cooking in the residential sector of developed nations: A review. *Food Policy*, *40*, 54–63. http://dx.doi.org/10.1016/j.foodpol.2013.02.003

Hefnawy, T. H. (2011). Effect of processing methods on nutritional composition and anti-nutritional factors in lentils (lens culinaris). *Annals of Agricultural Sciences*, *56(2)*, 57–61. http://dx.doi.org/10.1016/j.aoas.2011.07.001

Hewitt, J., et al. (2022). Not quite cooking on gas: Understanding biogas plant failure and abandonment in northern tanzania. *Renewable and Sustainable Energy Reviews*, *165*, 112600.

Husbands, A., & Cranford, S. (2019). A material perspective of wood, smoke, and bbq. *Matter*, *1(5)*, 1092–95.

IEA. (2020). World energy outlook 2020 (tech. rep.). International Energy Agency. Paris. https://www.iea.org/reports/world-energy-outlook-2020

Iessa, L., et al. (2017). What's cooking? unverified assumptions, overlooking of local needs and pro-solution biases in the solar cooking literature. *Energy Research & Social Science*, *28*, 98–108. http://dx.doi.org/10.1016/j.erss.2017.04.007

Iiyama, M., Njenga, M., De Leeuw, J., & Kimaro, A. A. (2014). Woodfuel. In J. De Leeuw, M. Njenga, B. Wagner, & M. Iiyama (Eds.), *Treesilience: An assessment of the resilience provided by trees in the drylands of eastern africa* (pp. 65–68). ICRAF.

Jouquand, C., et al. (2015). Optimization of microwave cooking of beef burgundy in terms of nutritional and organoleptic properties. *LWT - Food Science and Technology*, *60(1)*, 271–76.

Kapsalyamova, Z., Mishra, R., Kerimray, A., & Karymshakov, K. (2021). Why energy access is not enough for choosing clean cooking fuels? evidence from the multinomial logit model. *Journal of Environmental Management*, *290*, 112539. https://doi.org/10.1016/j.jenvman.2021.112539

Karunanithy, C., & Shafer, K. (2016). Heat transfer characteristics and cooking efficiency of different sauce pans on various cooktops. *Applied Thermal Engineering*, *93*, 1202–15. http://dx.doi.org/10.1016/j.applthermaleng.2015.10.061

Kumar, M., Kumar, S., & Tyagi, S. K. (2013). Design, development and technological advancement in the biomass cookstoves: A review. *Renewable and Sustainable Energy*

Reviews, *26*, 265–85. http://dx.doi.org/10.1016/j.rser.2013.05.010

Lam, N. L., et al. (2012). Kerosene: A review of household uses and their hazards in low- and middle-income countries. *Journal of Toxicology and Environmental Health Part B: Critical Reviews*, *15*, 396–432.

Leary, J., et al. (2019a). Ecook kenya cooking diaries (tech. rep.). University of Sussex. http://www.sussex.ac.uk/spru/research/projects/lct

Leary, J., et al. (2019b). Ecook myanmar cooking diaries working paper innovate project 132724 (tech. rep.). MECS. www.MECS.org.uk

Leary, J., Menyeh, B., Chapungu, V., & Troncoso, K. (2021). Ecooking: Challenges and opportunities from a consumer behaviour perspective. *Energies*, *14(14)*, 4345. https://www.mdpi.com/1996-1073/14/14/4345/htm

Lee, S., Choi, Y., Sang, H., & Junsoo, J. (2017). Effect of different cooking methods on the content of vitamins and true retention in selected vegetables. *Food Science and Biotechnology*. https://doi.org/10.1007/s10068-017-0281-1

Li, Y., et al. (2016). The effects of long-duration stewing combined with different cooking and heating methods on the quality of pork belly. *Journal of Food Processing and Preservation*, *40*, 94–102.

Lohani, S. P., Dhungana, B., Horn, H., & Khatiwada, D. (2021). Small-scale biogas technology and clean cooking fuel: Assessing the potential and links with sdgs in low-income countries – a case study of nepal. *Sustainable Energy Technologies and Assessments*, *46*, 101301.

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 for Sustainable Development*, *14(3)*, 161–71. http://dx.doi.org/10.1016/j.esd.2010.06.002

Maes, W. H., & Verbist, B. (2012). Increasing the sustainability of household cooking in developing countries: Policy implications. *Renewable and Sustainable Energy Reviews*, *16(6)*, 4204–21. http://dx.doi.org/10.1016/j.rser.2012.03.031

Martínez-gómez, J., et al. (2016). Analysis of lpg, electric and induction cookers during cooking typical ecuadorian dishes into the national efficient cooking program. *Food Policy*, *59*, 88–102.

McGee, H., McInerney, J., & Harrus, A. (1999). The virtual cook: Modeling heat transfer in the kitchen. *Physics Today*, *52(11)*, 30–36.

Mensah, E. E., et al. (2022). A comparative study of the effect of microwave and conventional heating methods on proximate composition of spiced millet porridge. *International Journal of Food Science and Nutrition*, *7(2)*, 1–6. www.foodsciencejournal.com

Mirza, U. K., Ahmad, N., & Majeed, T. (2008). An overview of biomass energy utilization in pakistan. *Renewable and Sustainable Energy Reviews*, *12(7)*, 1988–96.

Musafer, N. (2020). Biomass energy policy perspectives of sri lanka: A review. *International Journal of Scientific and Research Publications*, *10(12)*, 674–81.

Nandasena, S., Wickremasinghe, A. R., & Sathiakumar, N. (2012). Biomass fuel use for cooking in sri lanka: Analysis of data from national demographic health surveys. *American Journal of Industrial Medicine*, *55(12)*, 1122–28.

New, C. Y., et al. (2017). Microwave oven safety: A food safety consumer survey in malaysia. *Food Control*, *80*, 420–27. http://dx.doi.org/10.1016/j.foodcont.2017.05.024

Njenga, M., et al. (2019). Innovative biomass cooking approaches for sub-saharan africa. *African Journal of Food, Agriculture, Nutrition and Development*, *19(1)*, 14066–87.

Nunn, M. D., et al. (2016). Effects of cooking methods on sensory qualities and carotenoid retention in selected vegetables. *Journal of Food Quality*, *29(14940)*, 445–57. http://dx.doi.org/10.1016/j.foodchem.2011.03.070

Orsat, V., Raghavan, G. S. V., & Krishnaswamy, K. (2017). Microwave technology for food processing: An overview of current and future applications. In *The microwave processing of foods: Second edition* (pp. 100–116). Elsevier Ltd. http://dx.doi.org/10.1016/B978-0-08-100528-6.00005-X

Otte, P. P. (2014). A (new) cultural turn toward solar cooking—evidence from six case studies across india and burkina faso.

Energy Research & Social Science, *2*, 49–58. http://dx.doi.org/10.1016/j.erss.2014.04.006

Ozoh, O. B., et al. (2018). Cooking fuels in lagos, nigeria: Factors associated with household choice of kerosene or liquefied petroleum gas (lpg). *International Journal of Environmental Research and Public Health*, *15*, 641.

Paudel, D., Jeuland, M., & Lohani, S. P. (2020). Cooking-energy transition in nepal: Trend review. *Clean Energy*, *5*, 1–9.

Perera, K. K., & Sugathapala, A. G. (2002). Fuelwood-fired cookstoves in sri lanka and related issues. *Energy for Sustainable Development*, *6(1)*, 85–94. http://dx.doi.org/10.1016/S0973-0826(08)60302-6

Pohekar, S. D., Kumar, D., & Ramachandran, M. (2005). Dissemination of cooking energy alternatives in india—a review. *Renewable and Sustainable Energy Reviews*, *9*, 379–93.

Rahut, D. B., Ali, A., Mottaleb, K. A., & Aryal, J. P. (2019). Wealth, education and cooking-fuel choices among rural households in pakistan. *Energy Strategy Reviews*, *24*, 236–243. https://doi.org/https://doi.org/10.1016/j.esr.2019.03.005

Rahut, D. B., Mottaleb, K. A., & Ali, A. (2017). Energy consumption transition through the use of electricity for lighting and cooking: Evidence from bhutan. *Reinforced Plastics*, *18*, 11–21. http://dx.doi.org/10.1016/j.ref.2017.03.001

Ravindra, K., Kaur-sidhu, M., Mor, S., & John, S. (2019). Trend in household energy consumption pattern in india: A case study on the influence of socio-cultural factors for the choice of clean fuel use. *Journal of Cleaner Production*, *213*, 1024–34. https://doi.org/10.1016/j.jclepro.2018.12.092

Ravindranath, N. H., et al. (2005). Assessment of sustainable non-plantation biomass resources potential for energy in india. *Biomass and Bioenergy*, *29(3)*, 178–90.

Ray, S. (2021). Sensory properties of foods and their measurement methods. In M. S. Khan & M. S. Rahman (Eds.), *Techniques to measure food safety and quality: Microbial, chemical, and sensory* (pp. 345–81). Springer Nature Switzerland AG.

Rechkemmer, G. (2007). Nutritional aspects. In *Thermal processing of food: Potential health benefits and risks* (pp. 50–65).

Schenk, H. J., Horsfield, B., Krooss, B., Schaefer, R. G., & Schwochau, K. (1997). Kinetics of petroleum formation and cracking. In *Petroleum and basin evolution* (pp. 231–69).

Shaisundaram, V. S., et al. (2021). Design and analysis of novel biomass stove. *Materials Today: Proceedings*, *46*, 4054–58. https://doi.org/10.1016/j.matpr.2021.02.569

Shaisundaram, V. S., Chandrasekaran, M., Prabakaran, V., Karikalan, L., & Ramasubramanian, S. (2019). Design and experimental analysis of efficient biomass stove. *International Journal of Management, Technology And Engineering*.

Singh et al. (2021). Study on some aspects of adoption of solar cooking system: A review. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2021.05.323

Singh & Heldman, D. R. (2014). Heat transfer in food processing. In *Introduction to food engineering* (pp. 265–419).

Singh, P., & Kalamdhad, A. S. (2022). Assessment of small-scale biogas digesters and its impact on the household cooking sector in india: Environmental-resource-economic analysis. *Energy for Sustainable Development*, *70*, 170–80.

Singh, S., Swain, S., Singh, D., Salim, K., Nayak, D., & Roy, S. D. (2015). Changes in phytochemicals, anti-nutrients and antioxidant activity in leafy vegetables by microwave boiling with normal and 5% nacl solution. *Food Chemistry*, *176*, 244–53.

Smith, K. R., & Sagar, A. (2014). Making the clean available: Escaping india's chulha trap. *Energy Policy*, *75*, 410–14. http://dx.doi.org/10.1016/j.enpol.2014.09.024

Smithers, G. W. (2018). Food science – yesterday, today and tomorrow. In *Reference module in food science*. Elsevier.

Suleman, R., et al. (2020). Effect of cooking on the nutritive quality, sensory properties and safety of lamb meat: Current challenges and future prospects. *Meat Science*, *167(1)*, 108172. https://doi.org/10.1016/j.meatsci.2020.108172

Suresh, R., et al. (2016). Evaluation of the performance of improved biomass cooking stoves with different solid biomass fuel types. *Biomass and Bioenergy*, *95*, 27–34. http://dx.doi.org/10.1016/j.biombioe.2016.08.002

Thoday, K., Benjamin, P., Gan, M., & Puzzolo, E. (2018). The mega conversion program from kerosene to lpg in indonesia: Lessons learned and recommendations for future clean cooking energy expansion. *Energy for Sustainable Development*, *46*, 71–81. https://doi.org/10.1016/j.esd.2018.05.011

Thu, K., Kyaw, W., Ota, T., & Mizoue, N. (2020). Forest degradation impacts firewood consumption patterns: A case study in the buffer zone of inlay lake biosphere reserve, myanmar. *Global Ecology and Conservation*, *24*, e01340. https://doi.org/10.1016/j.gecco.2020.e01340

Tian, J., Chen, J., Ye, X., & Chen, S. (2016). Health benefits of the potato affected by domestic cooking: A review. *Food Chemistry*, *202*, 165–75. http://dx.doi.org/10.1016/j.foodchem.2016.01.120

Tyagi, S. B., Kharkwal, M., & Saxena, T. (2015). Impact of cooking on nutritional content of food. *DU Journal of Undergraduate Research and Innovation*, *1(3)*, 180–86.

Vadivambal, R., & Jayas, D. S. (2010). Non-uniform temperature distribution during microwave heating of food materials—a review. *Food and Bioprocess Technology*, *3*, 161–71.

Vaid, B. (2008). A study on nutrient profile and sensory characteristics of foods cooked by conventional methods, microwave cooking and solar cooking.

Vakalopoulos, A., et al. (2021). Household air pollution from biomass fuel for cooking and adverse fetal growth outcomes in rural sri lanka. *International Journal of Environmental Research and Public Health*, *18(4)*, 1878.

Wickramasinghe, A. (2011). Energy access and transition to cleaner cooking fuels and technologies in sri lanka: Issues and policy limitations. *Energy Policy*, *39(12)*, 7567–74. http://dx.doi.org/10.1016/j.enpol.2011.07.032

Wijayatunga, P. D. C., & Attalage, R. A. (2002). Analysis of household cooking energy demand and its environmental impact in sri lanka. *Energy Conversion and Management*, *43*, 2213–23.

Wright, C., Sathre, R., & Buluswar, S. (2020). The global challenge of clean cooking systems. *Food Security*, *12(6)*, 1219–40.

Yarmand, M., & Homayouni, A. (2011). Microwave processing of meat. In U. Chandra (Ed.), *Microwave heating*. IntechOpen.

Yasmin, N., & Grundmann, P. (2019). Adoption and diffusion of renewable energy – the case of biogas as alternative fuel for cooking in pakistan. *Renewable and Sustainable Energy Reviews*, *101*, 255–64. https://doi.org/10.1016/j.rser.2018.10.011

Table 1: Energy and time requirement for cooking pigeon pea (Akinoso & Oladeji, 2017)

Cooking stove	Highest energy (kJ)	Highest cooking time (min)
Kerosene	18450	306
LPG	52470	330
Electric	51200	190

Food item	Cooking method	Energy sources	Carbohydrates (%)	Protein (%)	Fat (Lipid) (%)	Main findings and remarks	Reference
Pork belly	stewing	LPG	-	18.86 ± 0.48	39.20 ± 3.28 SFA 39.930 ± 0.972	LPG flame heating significantly reduced the total saturated fatty acid content (P <0.01) compared to induction heating	Li et al., 2016
		Induction	-	17.42 ± 0.92	42.04 ± 3.48 SFA 41.550 ± 0.268		
Beans	boiling	Firewood	28.01 ± 1.14a	3.19 ± 1.14a	1.55 ± 1.14a	All three energy sources had a similar impact on the nutrients content of beans.	Eze, 2016
		LPG	26.72 ± 2.43a	3.33 ± 0.24a	1.65 ± 0.14a		
		Biogas	26.37 ± 1.09a	3.35 ± 0.66a	1.25 ± 0.49a		
Yams	boiling	Firewood	22.47 ± 0.24c	5.28 ± 0.17b	2.65 ± 0.07b	LPG cooked samples had significantly higher carbohydrate content and firewood cooked samples had significantly higher fat content.	Eze, 2016
		LPG	29.04 ± 1.47b	5.36 ± 0.06b	1.50 ± 0.28c		
		Biogas	20.92 ± 1.3c	5.18 ± 0.18b	0.95 ± 0.07c		
Rice	boiling	Firewood	19.96 ± 0.65g	2.32 ± 0.11e	1.25 ± 0.06f	Significant variations were observed, with higher carbohydrate content in LPG-cooked samples, higher protein content in firewood-cooked samples, and higher fat content in LPG-cooked samples.	Eze, 2016
		LPG	23.96 ± 1.85e	1.09 ± 0.19f	1.65 ± 0.07e		
		Biogas	22.47 ± 0.66f	2.19 ± 0.06e	1.05 ± 0.21g		
Milk	heating	LPG	4.67	2.41	3.47	Varying significant differences were observed in samples.	Martínez-gómez et al., 2016
		Electric	4.38	2.89	3.53		
		Induction	4.76	2.59	3.46		
Chochos	boiling	LPG	0	15.77	5.32		Martínez-gómez et al., 2016
		Electric	0.01	12.54	4.39		
		Induction	0	13.09	5.78		
Egg	boiling	LPG	4.43	12.59	9.06		Martínez-gómez et al., 2016
		Electric	3.4	13.36	10.09		
		Induction	2.6	14.17	10.18		
Broccoli	boiling	LPG	0.1	3.15	0.44		
		Electric	0.25	2.75	0.63		
		Induction	0.12	2.9	0.64		
Russian salad	boiling	LPG	20.31	2.26	0.56		
		Electric	19.31	1.74	0.59		
		Induction	12.94	1.92	0.59		
Fish	steaming	LPG	-	29.01	0.78	Protein and fat contents were higher in LPG steamed samples.	Martínez-gómez et al., 2016
		Induction	-	27.68	0.68		
Chicken	grilling	LPG	-	28.94	2.84	Protein and fat contents were higher in LPG grilled chicken.	
		Induction	-	28.06	2.79		
Millet porridge	boiling	LPG	-	7.01 ± 0.04b	0.91 ± 0.04e	Protein content is higher in LPG cooked sample. Fat content is higher in microwave cooked samples and increased with the microwave power.	Mensah et al., 2022
		Microwave 360W	-	6.76 ± 0.09b	1.14 ± 0.08d		
		600W	-	6.32 ± 0.18c	2.26 ± 0.18c		
		800W	-	5.79 ± 0.10d	3.14 ± 0.06b		

Table 2: Effect of cooking technique on macronutrients

Food item	Cooking method	Energy sources	Effects on micronutrients	Main findings and remarks
			$\beta-$carotene - 413 mg/100g	
Broccoli	boiling	LPG		No significant difference (P >0.05) in $\alpha-$carotene, $\beta-$carotene and Lutein/Zeaxanthin contents.
			Lutein/Zeaxanthin - 1608 mg/100g	
			$\beta-$carotene - 453 mg/100g	
		Induction		
			Lutein/Zeaxanthin - 1609 mg/100g	
			$\alpha-$carotene - 1623 mg/100g	
Carrot	boiling	LPG	$\beta-$carotene - 2514 mg/100g	$\alpha-$carotene, $\beta-$carotene and Lutein/ Zeaxanthin contents were not significantly different (P >0.05) in both methods.
			Lutein/Zeaxanthin - 572 mg/100g	
			$\alpha-$carotene - 1711 mg/100g	
		Induction	$\beta-$carotene - 2421 mg/100g	
			Lutein/Zeaxanthin - 674 mg/100g	
			$\alpha-$carotene - 36 mg/100g	
Green beans	boiling	LPG	$\beta-$carotene - 255 mg/100g	No significant difference (P >0.05) in $\alpha-$carotene, $\beta-$carotene and Lutein/ Zeaxanthin contents.
			Lutein/Zeaxanthin - 692 mg/100g	
			$\alpha-$carotene - 30 mg/100g	
		Induction	$\beta-$carotene - 261 mg/100g	
			Lutein/Zeaxanthin - 666 mg/100g	
Sweet potatoes	boiling	LPG	$\beta-$carotene - 2019 mg/100g	No significant difference (P >0.05) in $\alpha-$carotene, $\beta-$carotene and Lutein/Zeaxanthin contents.
		Induction	$\beta-$carotene - 2333 mg/100g	

Table 3: Effect of LPG and induction cooking on carotenoids in selected vegetables (Nunn et al., 2016).

Table 4: Micronutrients composition of beans, yam and rice cooked with firewood, LPG and biogas (Eze, 2016).

Food item	Cooking method	Energy sources	Vitamin B1 (mg/100 g)	Vitamin C (%)	Calcium (ppm)	Phosphorus (mg/100 g)
		Firewood	2.0 ± 1.14a	1.1 ± 1.14^{a}	28.0 ± 1.14^{b}	190 ± 1.41b
Beans	boiling	LPG	3.0 ± 1.14a	1.24 ± 0.01^{a}	32.0 ± 0.70^{a}	228 ± 2.82^{a}
		Biogas	-	0.28 ± 0.01a	24.0 ± 0.70c	228 ± 1.41^{a}
		Firewood	1.00 ± 0.07d	1.10 ± 0.57d	40.0 ± 2.83f	266 ± 1.41e
Yams	boiling	LPG	-	1.10 ± 1.41d	48.0 ± 2.83e	190 ± 1.41d
		Biogas	1.00 ± 0.07d	0.55 ± 0.07d	32.0 ± 0.71d	32.0 ± 0.71d
		Firewood	1.00 ± 0.07f	0.41 ± 0.13f	48.0 ± 1.41g	190 ± 2.82g
Rice	boiling	LPG	1.00 ± 0.07f	1.46 ± 0.19g	32.0 ± 1.41f	190 ± 1.41g
		Biogas	1.00 ± 0.07f	0.28 ± 0.03f	32.0 ± 1.41f	152 ± 1.41f

Cooking method	Effects on organoleptic properties	Conclusion	Reference
Broccoli/ Carrots/ Green beans/ Sweet potatoes Conventional boiling Induction boil	Colour - No significant difference ($P > 0.05$) was observed in broccoli, carrots, and green beans. In sweet potatoes, microwave steamed samples were judged to be significantly darker ($P < 0.05$) than those that were conventionally boiled but not those boiled using induction. Flavour - The flavor scores for sweet potatoes were similar. In terms of broccoli, carrots and green beans cooked by microwave steaming, the flavour was significantly more ($P < 0.05$) intense compared to conventional boiling as well as induction boiling for broccoli and carrots. Texture – the texture was significantly different ($P < 0.05$) in broccoli prepared by both methods. Sample prepared by conventional boiling was significantly less ($P < 0.05$) firm in texture than that prepared by microwave steaming, while that prepared by induction boiling was in the middle. Induction-boiled carrots had a firmer texture than conventionally boiled carrots. Green beans that were induction boiled were judged to have a significantly firmer ($P < 0.05$) texture than those cooked by conventional boiling.	Induction cooking is better than conventional boiling in terms of sensory characteristics.	Nunn et al., 2016
Pigeon Pea (*Cajanus cajan*) Normal and controlled cooking of kerosene, LPG, electric and charcoal stoves	No significant difference ($P > 0.05$) among all the samples evaluated for taste, colour and overall acceptability. There was a significant difference ($P < 0.05$) in the texture of pigeon pea cooked under pressure compared to other forms of cooking, although there was no significant difference between pigeon pea cooked under pressure and with a kerosene stove.	The method of cooking carried out do not affect taste, colour and overall acceptability of cooked pigeon pea.	Akinoso and Oladeji, 2017
Rice/ Beans/ Yams/ Firewood LPG	There was no significant difference ($P > 0.05$) in overall acceptability in beans cooked with LPG and firewood, although colour and appearance are significantly different. In yams, significant differences ($P < 0.05$) were recorded in colour, appearance, flavour and overall acceptability while there was no significant taste, after taste and mouthfeel difference between yam cooked with LPG and firewood. There was no significant difference in flavour, taste, aftertaste and mouthfeel between rice cooked with firewood and LPG, while colour and appearance were significantly different.	There are varying significant differences in the sensory properties of rice, beans and yam when cooked with firewood and LPG.	Eze, 2016
Orange with oatmeal/ grilled chicken/ steamed fish/ broccoli/ Russian salad Induction cooking LPG cooking	Significant differences ($\alpha = 0.001$) were observed in taste in orange with oatmeal, grilled chicken, steamed fish and broccoli and it was not perceptible in Russian salad. The degree of difference in these four dishes was moderate.	Orange with oatmeal, grilled chicken and broccoli were more acceptable when cooked with induction cooker. In Russian salad and steamed fish, both techniques were acceptable.	Martinez-gómez et al., 2016
Ground nuts/ Sweet corn/ Rice/ Mung dal Microwave Solar cooking	No significant difference in organoleptic properties between microwave and solar cooking.	Sensory properties are not affected with the two cooking methods.	Vaid, 2008

Table 5: Effect of cooking energy source on sensory properties