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ABSTRACT

This study was undertaken to assess indoor air pollution and potential exposure to particulate matters (PMs—PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}), and total suspended particles [TSP] and total volatile organic compounds [TVOCs] during baking of Ethiopian traditional staple food, *Injera* using different types of stoves at Addis Ababa, Ethiopia. The geometric mean (GOM) of PMs pollutant using clean, improved, and traditional stoves were ranged 10.8–235, 23.6–462, and 36.4–591 $\mu g/m^3$, respectively. The GOM of TVOCs in the wet and dry season using the clean, improved, and traditional stoves were 1,553, 2,234, 4,421, and 845, 1,214, and 2,662 $\mu g/m^3$, respectively. The health risk of an exposed person to $PM_{2.5}$, PM_{10}, and TSP during baking of *Injera* was characterized and the results showed only baking of *Injera* using any of the stove types does not cause health problems to the baker. However, the percent contribution to the total chronic intake is high up to 38%.

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Biomass fuel; cook stove; Ethiopia; indoor air pollution; Injera; particulate matter; total volatile organic compound

Introduction

Nearly 50% of the world population and 90% of the developing world continue to rely on biomass fuel for their household energy need such as for cooking, lighting, and heating. The emission from burning biomass fuel affects nearly 3 billion people, particularly the women and young children.[1,2] Indoor combustion of biomass fuels, tobacco smoking, outdoor air pollutants, emissions from construction materials and furnishings, and improper maintenance of ventilation and air conditioning systems are the most common sources of indoor air pollution. From these sources, combustion of biomass fuels used for cooking, heating, and lighting is the primary cause of indoor air pollution in developing countries.[3–7]

The use of biomass fuel, as energy, results in the emissions of different types of pollutants such as total volatile organic compounds (TVOCs), CO, NO_2, SO_2, and particulate matters (PMs) with different aerodynamic diameters. Among the substances in polluted air, PMs with different aerodynamic diameter and TVOCs are significant components, and these are the cause of the health concern in the world. TVOCs include compounds such as formaldehyde, benzene, 1,3-butadiene, polycyclic aromatic hydrocarbons like benzo[a]pyrene which have shown to cause short- and long-term adverse health effects. TVOCs and PM with a wide range of aerodynamic diameters released during the combustion of biomass fuel and traffic emissions cause significant air-quality problems in most developing countries in general and Ethiopia in particular.[8–12] Once TVOCs and PMs enter into the human body through any of the three exposure pathways (inhalation, ingestion, and dermal contact), they can cause either the short-term adverse effects including conjunctive irritation, nose and throat discomfort, headache and sleeplessness, allergic skin reaction, nausea, fatigue and dizziness, or the long-term adverse effects including loss of coordination, leukemia, anemia, cancer and damage to the liver, kidney, and central nervous system.[13–16]

According to a 2010 report by World Health Organization, WHO, indoor smoke from biomass fuel combustion causes about 21% of deaths from lower respiratory infections, 35% of deaths from chronic obstructive pulmonary disease, and about 3% of deaths from lung cancer. The total impact of indoor pollution contributed 3.9% of all deaths in low- and middle-income countries in the year 2004.[17] The number of victims affected by smoke from biomass

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fuel has been increasing. In 2014, WHO has reported that 4.3 million people prematurely die annually due to the attribution of indoor air pollution from biomass smoke during cooking.[18] Despite these impacts on human, the use of biomass as fuel source is still used in both urban and rural areas, even though its rate of consumption is decreasing in urban areas.

The use of biomass fuel is more significant in low-income countries, such as in Sub-Saharan Africa compared to developed countries.[8–10] In Sub-Saharan Africa, about 90–95% of domestic energy is used for cooking which depends on biomass fuels. In Ethiopia, biomass fuel is the major source of energy consumption for different applications. For more than 90% of the Ethiopian population, the only energy used for cooking, heating, and lighting is obtained from biomass fuel, of which 99% is derived from firewood, charcoal, crop residues, and leaves. Among these, firewood is the primary source of energy for domestic use.[19] The amount of biomass fuel used for cooking depends on the efficiency of the stove and the type of food prepared. For instance, an average Ethiopian household baking *Injera* (a flatbread mostly made from *Teff* flour and baked upon a circular griddle or skillet pan) accounts for over 50% of all primary energy consumption and over 75% of all household energy consumption. This might be due to the low efficiency of the stove used for baking *Injera*.[20] Although baking *Injera* has been a unique culture for Ethiopians and Eritreans, both living in their country and abroad, the tradition is now expanding among the people in the neighboring countries, Somalia and Sudan.[21]

Different researchers have carried out some pilot- and cohort studies for the determination of indoor and ambient air pollutants, including CO, NO_2, $PM_{2.5}$, PM_{10}, and TSP in different parts of Ethiopia.[22–25]. Most of the results of these studies exceeded the US EPA and WHO standard, mainly, their levels in indoor were high. This might be due to living in a crowded and poorly ventilated house, type of stove and fuel used, and limited access to separate cooking and living areas in rural and urban homes which is visible features of living conditions in Ethiopia. In general, air pollution and its health impact relation were studied based on the measurement of the air pollutants at a fixed place, which does not predict accurate exposure assessment of the pollutants. Thus, using personal exposure data at different microenvironments rather than at fixed environments is the better method of exposure assessment and for identifying the role of each microenvironment to the personal exposure.[26–29] However, almost in all the exposure assessment to the PM studies conducted so far in Ethiopia is based on 24 h measurement at a fixed site for indoor and outdoor air that might not show the real exposure of a person. This is because the person does not stay at the home or outdoor for 24 h. Although the exposure to a high level of the PM with short period showed health problems, studies conducted in Ethiopia lacks information related to quantification and assessment of short-term exposure (from 1 h to several hours) to PM pollutants which come from different activities, more importantly activities which emit a high level of pollutants.[12,30,31] Both quantification and short-term exposure assessment to indoor TVOCs at the microenvironment level have not been reported so far.

Consequently, the real-time personal exposure monitoring, coupled with the individual activity data is required for assessing the exposure risk population groups, the level and frequency of exposure. As a result, such type of measurement should have been carried out at the microenvironments level, especially where high exposure occurs.[32] Nevertheless, none of the Ethiopian studies conducted so far measured indoor air-quality at the individual microenvironment. Among the cooking activities that use biomass fuels in Ethiopia, baking of *Injera* is the major source of indoor air pollution due to the high consumption of biomass fuel and the design of the traditional stoves. *Injera* baking is traditionally done by women in Ethiopia. Thus, the women involved in baking *Injera* may have higher risks of health problems associated with the exposures of particulates matter, carbon monoxide, and other TVOCs. In addition, the level of PMs and TVOCs pollutants emitted from different stove types in the baking of *Injera* might be different. Hence, the measurement of such pollutants is vital in selecting better stove types and estimating health impacts on the baker. However, to the best of our knowledge, no studies have been carried out for the quantification of PM with a different aerodynamic diameter (ranged from 1 to 50 μm [TSP]) and TVOCs while baking *Injera* using clean, improved, and traditional stoves in individual households at Addis Ababa and anywhere in Ethiopia and the associated health risk assessment of the *Injera* baker.

Therefore, the present study is mainly focused on assessing the short-term exposure of Ethiopian women to PMs and TVOCs pollutants during the baking of *Injera* in 45 individual households. The study sites were selected in three different sub-cities of Addis Ababa. The influence of varying the type of biomass fuel, and the kinds of the stove (clean, improved, and traditional) were used to compare the levels of emissions during the baking. The results were then applied to estimate the health risk on the bakers due to the lifelong chronic exposure to the stove-emission of $PM_{2.5}$, PM_{10}, and TSP.

Materials and methods

Description of study area

Ethiopia is the second most populous country in Africa (the estimate for 2019 is 112 million), and metropolitan Addis Ababa has a population exceeding 3 million. The city has been growing at a rate of 2.1% from 1994 to 2010.[10,11] The city is situated at the center of the country at an altitude varying between 2,200 and 2,800 m above the sea level, between latitude 9.0300°N and longitude 38.7400°E. Average minimum and maximum annual temperatures are range from 9.53 to 23.2 °C, and the average annual rainfall is 1,170 mm.[25,33]

Since the level of outdoor pollution can influence personal exposure to indoor air pollution, the selection of sub-cities before the selection of households is vital. Thus, the three representative sub-cities (Arada, Gulelle, and Akaki Kality) were selected as sampling sites based on the altitude differences, socioeconomic activities, and population density. Arada sub-city is mainly characterized by its high population density, medium traffic intensity, and no industries. While Gulelle sub-city is characterized by a limited number of industries, medium traffic intensity, low population density than Arada sub-city, whereas Akaki Kality sub-city is characterized by low population density than the other two sub-cities, heavy industrial activities, and high traffic congestion. Accordingly, Arada, Gulelle, and Akaki Kality were selected as sampling sub-cities for the measurement of indoor air pollutants during baking of *Injera* using different fuel types during wet and dry seasons. The sampling households were selected based on the stove type they use and the willingness of families allowing the researcher in their house for air-quality measurement. A total of 45 households (15 households from each sub-city) were selected randomly due to general procedure similarity in the baking of *Injera*.

Description of stove types

Different types of stoves are used for the baking of *Injera* in which the variations in the stoves are either in the design or in the fuel they use. Thus, the clean stove (Electric stove, Mitad in Amharic) looks like a griddle made from a circular-shaped clay that contains an electric resistance heating wire coils embedded inside, which is used as a source of heating. The improved stoves (Mirt Midja, in Amharic) have a different design; however, in this study, we have used a stove with a similar design to the clean stove that most widely used in Addis Ababa. However, this stove has some differences in the design from the clean-stove in that it has a chimney or flue, which allows the removal of fumes outside the kitchen and the small hole used for fuel addition and for fire ignition startup. The traditional-stoves (three-stone) have a different design than both the clean and improved stoves in which the stove is supported on three stone-legs and open fire is applied. Only a fraction of the heat from the open fire in the traditional stove is used for baking the *Injera* placed on the griddle or skillet pan. Both improved and traditional stoves use similar types of biomass as fuel sources. Figure 1 shows the picture and sketch of three types of cook stove used for baking the *Injera*.

PMs and TVOCs measurement methods

The level of TVOCs during the baking of *Injera* using three different types of stove and fuel were measured in 45 households using a simple and portable sensor (AEROQUAL series 500; Aeroqual Limited, Auckland, New Zealand) with 2 min interval. The sampler was calibrated according to the manufacturer procedure at the flow rate of 0.5 L/min while measuring. The instrument uses photo iodide detector as a detector. The sensor was warmed up to burn off any contaminants (the monitor was first switched on which warmed up for 3 min). Then, a zero calibration was done before each measurement using zero grade air cylinder, and the reading was stabilized after 10 min. Finally, the instrument was ready for measurement and it kept side by side to the sampler of PMs at the same kit. The measurements were carried out between July 1 and September 30, 2015, for the wet season and November 15, 2015, and March 10, 2016, for the dry season in two rounds each. The two seasons (the wet and dry) were selected for this study because the concentration of pollutants emitted during combustion depends highly on seasonal variation. Besides, the moisture content of the biomass fuel used for baking is usually different in the wet and dry seasons. Typically, the *Injera* baker stands continuously next to the stove during the baking until baking is completed which last few hours. Hence, the sampler was put

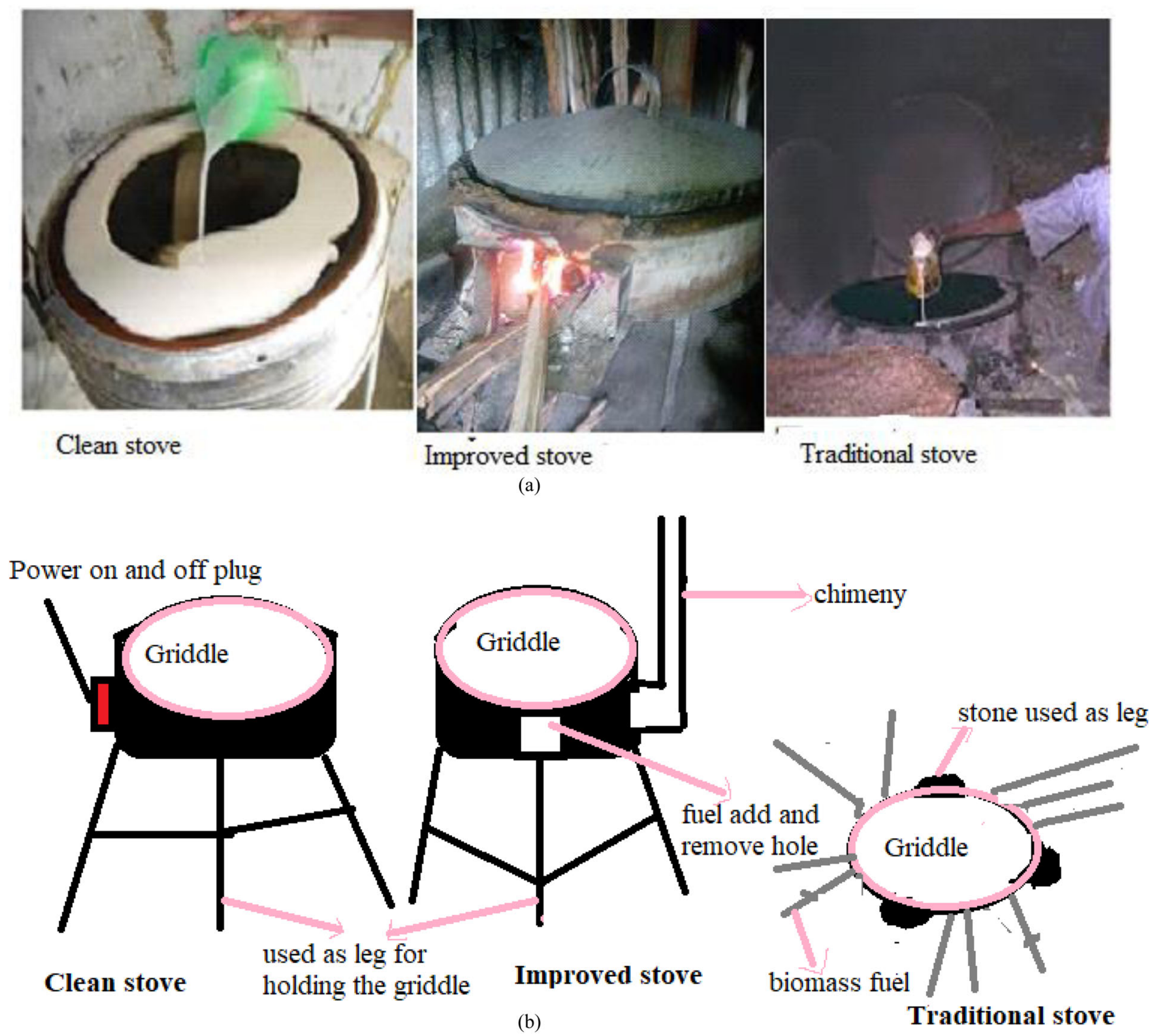

Figure 1. (a) The pictures of three types of cook stove used for baking the *Injera*. (b) The sketch of three types of cook stove used for baking the *Injera*.

1.5 m above the ground and 1 m from the stove during baking *Injera*, which is the most appropriate breathing zone of the baker. During the baking time, no other activities were performed to prevent interference from such operations. The measurements were started 10 min before starting the baking, and continued the measurement until the baking ended.

The level of PMs while baking the *Injera* was measured by a portable sensor called AROCET531S (Met One Instrument., Inc. Grants Pass, OR 07526, USA). The instrument contains an ambient air inlet nozzle, which is used to reduce turbulence in air sampling and measuring room temperature and humidity. It also has a temperature and humidity sensor, for measurement of room temperature and humidity, respectively. Moreover, the instrument uses the manufacturer calibrated constant flow rate of 2.83 L/min. The PMs sampling instrument was put side by side to the TVOCs sampling instrument and follow a similar procedure except using a different calibration method. Thus, it uses zero count test calibration which was performed by following the manufacturer procedure weekly. A zero-count filter was attached to the inlet nozzle until the smallest particle size displayed a count less than or equal to one. The limit of detection of the PM sensor is 0.1 $\mu g/m^3$. The instrument uses a laser-diode-based optical sensor, in which it uses light scatter technology to distinguish, measure, and count particles. The optical sensor transforms scattered light into electrical signals, which are processed to provide mass measurements. Finally, the data has logged to the computer by using a cable provided by the company. We used PM sensors that use laser and optical sensors to measure light scattered from particles

Table 1. Some characteristics of kitchens in the selected households at different sampling sites.

	Fuel type					
Site code	Wet season	Dry season	Ventilation type	Kitchen position	Family size	Volume of kitchen (m^3)
ar1A	Electricity	Electricity	Both window and door	LR	6	7.50
ar1B	Electricity	Electricity	Both window and door	LR	2	21.0
ar1C	Electricity	Electricity	Window only	NLR	4	10.2
ar1D	Electricity	Electricity	Both window and door	LR	5	20.9
ar1E	Electricity	Electricity	Both window and door	LR	4	16.8
ar2A	Wood and leaves	Leaves and sawdust	Door only	NLR	3	21.1
ar2B	Leaves only	Leaves and sawdust	Door only	NLR	5	11.0
ar2C	Leaves only	Leaves only	Door only	NLR	3	15.0
ar2D	Leaves only	Wood only	Door only	NLR	5	10.1
ar2E	Leaves only	Leaves and sawdust	Door only	NLR	4	28.0
ar3A	Leaves only	Wood only	Door only	NLR	4	10.2
ar3B	Wood and leaves	Leaves only	Door only	NLR	2	10.2
ar3C	Wood only	Leave only	Both window and door	NLR	4	42.0
ar3D	Wood only	Leaves only	Both window and door	NLR	7	13.3
ar3E	Wood and leaves	Leaves only	Door only	NLR	4	11.3
gu1A	Electricity	Electricity	Door only	NLR	4	13.8
gu1B	Electricity	Electricity	Window only	LR	5	22.5
gu1C	Electricity	Electricity	Both window and door	NLR	5	42.0
gu1D	Electricity	Electricity	Both window and door	LR	7	42.0
gu1E	Electricity	Electricity	Door only	LR	4	25.2
gu2A	Wood and leaves	Leaves only	Both window and door	NLR	7	15.0
gu2B	Wood only	Wood and leaves	Both window and door	NLR	5	14.3
gu2C	Leaves and sawdust	Wood only	Door only	NLR	4	15.4
gu2D	Leaves only	Wood only	Door only	NLR	5	21.7
gu2E	Leaves only	Wood only	Door only	NLR	5	7.98
gu3A	Leaves only	Leaves only	Door only	NLR	4	13.5
gu3B	Wood and leaves	Leaves only	Door only	NLR	4	11.9
gu3C	Leaves only	Wood and leaves	Door only	NLR	4	56.0
gu3D	Leaves and sawdust	Wood only	Both window and door	NLR	4	18.9
gu3E	Wood only	Leaves only	Both window and door	NLR	4	9.50
ak1A	Electricity	Electricity	Both window and door	LR	3	15.0
ak1B	Electricity	Electricity	Both window and door	NLR	5	12.2
ak1C	Electricity	Electricity	Both window and door	NLR	3	28.0
ak1D	Electricity	Electricity	Both window and door	NLR	5	23.2
ak1E	Electricity	Electricity	Both window and door	NLR	3	17.4
ak2A	Wood only	Leave only	Both window and door	NLR	5	15.6
ak2B	Wood only	Leave only	Both window and door	NLR	3	19.4
ak2C	Wood only	Wood only	Both window and door	NLR	3	18.7
ak2D	Wood only	Wood only	Both window and door	NLR	5	25.6
ak2E	Wood only	Wood only	Both window and door	NLR	5	20.9
ak3A	Leaves and sawdust	Leaves only	Both window and door	NLR	4	10.0
ak3B	Leaves only	Leaves only	Both window and door	NLR	2	12.5
ak3C	Leaves only	Leaves and sawdust	Both window and door	NLR	3	15.0
ak3D	Wood only	Leaves only	Both window and door	NLR	5	21.0
ak3E	Wood only	Wood only	Both window and door	NLR	4	18.0

Site code: ar, Arada sub-city; gu, Gulelle sub-city; ak, Akaki Kality sub-city; 1, 2, and 3 indicates stove types clean, improved (merit), and traditional (3 stone), respectively; A, B, C, D, and E represent different households in each sub-city; LR, kitchen found in living room; NLR, kitchen found in separate room from living room, not in living room.

passing through the laser beam. The optical sensor transforms scattered light into electrical signals, which are processed to provide mass measurements.

Furthermore, different characteristics of the houses such as the volume of the cooking room, the types of ventilation and the family sizes were recorded. The survey data related to demographic characteristics was collected by simply asking the bakers, and volumes of the home and ventilation types/sizes were measured by using tape. The details are given in Table 1.

Data analysis

PMs data were uploaded to a computer from sampling instruments using the cable and software provided by the manufacturer and data filtering, and reduction was made using different software. TVOCs were recorded in the notebook at a 2-min interval and fed to a computer manually. The statistical data analysis was carried out using IBM SPSS version 20.0, Microcal^{TM} Origin version 6.0 (Micrical software, Inc. USA) and Microsoft Excel 2013. Kruskal–Wallis test was used to evaluate the significance of the differences in PMs and TVOCs among stove types used for baking of *Injera*. The Wilcoxon signed-rank test was applied to evaluate the significant difference in concentration of PMs and TVOCs across seasons. Also, a Shapiro–Wilks statistical test was used to determine whether the data fit a normal or log-normal distribution functions. The concentration data was described better by using the log-normal distribution function than the normal distribution where the GOM and geometric standard deviation (GSD) were used to report the data. The significant difference for all the tests was set to 0.05.

Results

Characteristics of households

Among the selected households 23.3% of households have used wood only, 7.78% of households have used combined wood with leaves, 7.78% of households have used combined leaves with sawdust, 33.3% of households have used electricity, and 27.8% of households have used leaves only as fuel in both the wet and dry seasons during the measurement period. As far as the kitchen location is concerned, 8 kitchens were in the living room and 37 kitchens were found separately from the living room. The main ventilations found in the kitchens, include 2 households that have windows, 16 households have a door with no windows, and 27 kitchens have both a window and a door for ventilation regardless of natural ventilation. The family size and the kitchen volume for selected households ranged from 2 to 7 and 7 to 56 m^3, respectively. The average frequencies of *Injera* baking are approximately 2 times/week. Table 1 shows the detailed information of the kitchen characteristic, including the type of fuel, ventilation type, the volume of the kitchen, and family size of the selected households in this study.

The level of PMs and TVOCs

The common practice of PM measurement involves the two-particle ranges that the U.S. Environmental Protection Agency classifies as inhalable particles PM_{10} and inhalable fine particles $PM_{2.5}$. New categories like $PM_{1.0}$ and $PM_{4.0}$ are also finding their way into air quality monitoring devices as these new outputs provide additional information to the traditional PM_{10} and $PM_{2.5}$ levels, enabling a better assessment of PMs impact on health. We chose to conduct multi-range particle size measurements PMs (PM_1, $PM_{2.5}$, PM_4, PM_7, PM_{10}), and total suspended particles [TSP] to get a full picture of the PMs emission during the baking of *Injera*.

In this study, the concentration of PMs and TVOCs are measured during the baking of *Injera* using clean, improved, and traditional stoves. Shapiro–Wilks test is applied to the concentration data across each stove type at different seasons, and the result showed that the data is not normally distributed. Therefore, all concentration data is reported as geometric mean (GOM) and GSD for both seasons. The GOM concentration of PMs and TVOCs using clean, improved, and traditional stoves in the wet and dry seasons are summarized in Table 2. The room temperature and relative humidity of room are also recorded during the baking of *Injera* using the clean, improved, and traditional stoves during dry and wet seasons, and the results are given in Table 2.

The amount of PMs pollutant measured during the wet season using clean, improved, and traditional stoves ranged $37.0 - 235$, $72.8 - 462$, and $50.3 - 591\ \mu g/m^3$, respectively; whereas, the levels of TVOCs are 1,553, 2,234, and 4,421 $\mu g/m^3$, respectively. The maximum and the minimum amount are recorded at the traditional and clean stoves, respectively, for both PMs and TVOCs. Furthermore, the levels of TVOCs are much higher than the levels of PMs emission from each type of stove.

Kruskal–Wallis sample test is applied to the data obtained for clean, improved, and traditional stove, which showed that both PMs and TVOC pollutants have a significant difference in their concentration across each stove ($p = 0.00$). However, the difference is not recognized where it occurred. Therefore, Kruskal–Wallis K independent sample test is further applied by selecting the case. Thus, emissions from the clean stove is compared to that of the traditional stove and the improved stove, and the results showed a significant difference in the concentration of PMs and TVOCs ($p < 0.00$). Likewise, traditional and improved stoves are compared, which showed a significant difference in TVOCs and PMs ($p < 0.00$).

The average time used for baking the *Injera* during the wet season in the selected households using the clean, improved and traditional stoves are 73.0, 61.7, and 68.5 min, respectively. The room temperature and relative humidity of the kitchens using the clean, improved and traditional stoves are 22.8, 27.2, and 26.1 °C and 57.2, 41.3, and 44.8%, respectively.

On the other hand, the amount of PMs measured at the dry season by using the clean, improved, and traditional stoves ranged $10.5 - 119$, $23.6 - 265$, and $36.4 - 728\ \mu g/m^3$, respectively. The levels of TVOCs are 845, 1,214, and 2,662 $\mu g/m^3$ for the clean, improved, and traditional stove, respectively. Thus, for both types of pollutants, the lowest amount is found using the clean stove and the highest amount is found using the traditional stove. As observed in the wet season, the levels of TVOCs in the dry season are also much higher than the levels of PMs emission from

Table 2. The concentration of PMs, TVOCs, kitchen volume, AT, RH, and time used for baking the *Injera* by using different types of the stove (clean, improved [merit], and traditional [3 stone]) stoves during wet and dry seasons (GOM ± GSD).

Season type	Stove type	PM_1 (μg/m³)	$PM_{2.5}$ (μg/m³)	PM_4 (μg/m³)	PM_7 (μg/m³)	PM_{10} (μg/m³)	TSP (μg/m³)	TVOCs (μg/m³)	K volume (m³)	AT (°C)	RH (%)	Time (min)
Dry	Clean	10.5 ± 2.0	22.4 ± 3.0	38.3 ± 3.6	63.6 ± 3.3	84.1 ± 3.0	119 ± 2.7	845 ± 2.5	19.1 ± 1.6	24.7 ± 1.2	35.8 ± 1.3	75.5 ± 1.2
	Improved	23.6 ± 1.3	57.4 ± 3.6	92.5 ± 4.2	139 ± 4.0	183 ± 3.8	265 ± 3.5	1,214 ± 2.3	16.4 ± 1.4	26.7 ± 1.2	28.1 ± 1.4	83.1 ± 1.2
	Traditional	36.4 ± 2.2	174 ± 2.9	356 ± 3.0	498 ± 2.7	594 ± 2.5	728 ± 2.3	2,662 ± 2.1	15.6 ± 1.7	26.3 ± 1.2	31.5 ± 1.5	75.9 ± 1.3
Wet	Clean	37.0 ± 1.9	74.0 ± 2.2	111 ± 2.5	156 ± 2.5	189 ± 2.4	235 ± 2.4	1,553 ± 2.3	19.1 ± 1.6	22.8 ± 1.3	56.2 ± 1.3	73.0 ± 1.2
	Improved	72.8 ± 1.7	144 ± 2.4	208 ± 2.7	298 ± 2.7	363 ± 2.7	462 ± 2.7	2,234 ± 2.6	16.4 ± 1.4	26.2 ± 1.2	44.2 ± 1.3	61.7 ± 1.2
	Traditional	50.3 ± 2.5	207 ± 3.1	358 ± 3.3	449 ± 3.1	502 ± 3.0	591 ± 2.1	4,421 ± 2.1	15.6 ± 1.7	27.0 ± 1.2	42.3 ± 1.4	68.5 ± 1.3

PMs, particulate matters; TVOCs, total volatile organic compounds; GOM, geometrical mean; GSD, geometrical standard deviation; TSP, total suspended particles; K volume, kitchen volume; AT, atmospheric room (kitchen) temperature; RH, relative humidity of the kitchen.

Table 3. Wilcoxon signed-rank test results for emissions of PMs, TVOCs, AT, and RH while using clean, improved, and traditional stove between dry and wet season.

	Clean stove		Improved stove		Traditional stove	
	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
PM_1 at wet–PM_1 at dry	−18.6[a]	0.00	−16.6[a]	0.00	−8.55[a]	0.00
$PM_{2.5}$ at wet–$PM_{2.5}$ at dry	−18.4[a]	0.00	−12.5[a]	0.00	−5.23[a]	0.00
PM_4 at wet–PM_4 at dry	−17.5[a]	0.00	−10.4[a]	0.00	−2.42[a]	0.02
PM_7 at wet–PM_7 at dry	−16.6[a]	0.00	−10.8[a]	0.00	−1.31[a]	0.19
PM_{10} at wet–PM_{10} at dry	−16.5[a]	0.00	−10.5[a]	0.00	−0.66[a]	0.51
TSP at wet–TSP at dry	−15.9[a]	0.00	−8.9[a]	0.00	−0.33[a]	0.74
TVOCs at wet–TVOCs at dry	−11.6[a]	0.00	−6.57[a]	0.00	−9.11[a]	0.00
AT at wet–AT at dry	−8.93[b]	0.00	−5.26[a]	0.00	−3.00[a]	0.00
RH at wet–RH at dry	−19.4[a]	0.00	−8.44[a]	0.00	−12.2[a]	0.00

PMs, particulate matters; TSP, total suspended particles; TVOCs, total volatile organic compounds; AT, atmospheric room (kitchen) temperature; RH, the relative humidity of the kitchen.
[a]Based on negative ranks.
[b]Based on positive ranks.

each stove. The average time used for baking *Injera* during the dry season using the clean, improved, and traditional stoves are 75.5, 83.1, and 75.9 min, respectively. People who used traditional stoves spent on average more baking-time during the dry season than the baking-time during the wet season. The difference could be because people bake more *Injera* during the dry season than in the wet season. The temperature and the relative humidity of the kitchens, during the baking of *Injera* by the clean, improved, and traditional stoves are 24.7, 26.7, and 26.3 °C and 35.3, 28.1, and 31.5%, respectively.

Kruskal–Wallis test is also applied to the data for the clean, improved, and traditional stoves and the result showed a significant difference in the concentration of PMs and TVOCs ($p < 0.00$). Besides, Kruskal–Wallis K independent sample test is carried out for the individual comparison to see where this difference has occurred. Consequently, the clean stove is compared to improved and traditional stoves separately, and the results showed a significant difference in PMs and TVOCs concentration ($p < 0.00$). Similarly, improved and traditional stove are compared which showed a significant difference in both PMs and TVOCs concentration ($p < 0.00$). This variation might be due to the differences in stove design, fuel moisture, fire status, and ventilation type.

Generally, the level of PMs emission found in this study using the improved stove is lower than the PMs levels found using the traditional stoves, which shows a similar trend with the level of particulate matter ($PM_{3.5}$) measured in the Guatemalan community. The level of $PM_{3.5}$ at the Guatemalan community using the improved stove is lower than that of the traditional stove.[34] Similarly, the concentrations of $PM_{2.5}$ using the improved and traditional stoves found in this study is compared to the previous study conducted in Addis Ababa, and the results showed that the concentrations of $PM_{2.5}$ found in this study is lower than that of an earlier study conducted in Addis Ababa.[25] This variation might be due to the type of biomass fuel, the moisture content of the fuel, amount of fuel used, duration of measurement, fuel condition, ventilation type, the location of the sampler, and the type of cooking conducted.[35,36]

Temporal variation of PMs and TVOCs

The temporal variation of PMs, TVOCs, AT, and RH is calculated using Wilcoxon signed-rank test within the clean, improved and traditional stoves, and the results are shown in Table 3. Wilcoxon signed-rank test showed a significant difference in concentration of PMs and TVOCs within each stove type between

Table 4. Comparison of percentage exposure reduction to PMs, TSP, and TVOCs by clean and improved stoves as compared to traditional stove, and clean stove as compared to the improved stove.

PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs	Remarks
53.9	78.6	81.7	79.0	76.9	74.6	66.6	Clean vs. traditional stove
12.3	56.0	63.9	59.9	55.7	49.3	54.5	Improved vs. traditional stove
47.4	51.7	49.5	47.6	47.9	49.8	26.5	Clean vs. improved stove

PMs, particulate matters; TSP, total suspended particles; TVOCs, total volatile organic compounds.

dry and wet season at $p < 0.05$, except, PM_4, PM_7, and PM_{10} did not show a significant difference at the traditional stove. The relative humidity and temperature of the baking room also showed a significant difference in the dry and wet seasons within the stove type which might affect resuspension rate or the dispersion of the pollutant. Consequently, the variation in concentration of pollutants might come from this variation. The moisture content of the fuel, the status of the fire and the formation of secondary pollutants (through condensation and coagulation) during the measurements might also be the reason for the difference in PMs and TVOCs concentration. Secondary pollutants can be formed with the pollutants released from the baking process itself, without the involvement of any other pollutants emitted from other sources.

The percent exposure reduction by the clean and improved stove

Previous studies have shown that the use of clean stoves or improved stoves during cooking reduced the generation of air pollutants than of the traditional stove.[34] This study has also confirmed a similar trend in reducing exposure of PMs and TVOCs pollutants during the baking of *Injera* using such types of stove. The details of the percent exposure reduction by using the clean and improved stove instead of the traditional stove and clean stove as compared to the improved stove during the baking of *Injera* are shown in Table 4. The percent exposure reductions are calculated by using overall GOM regardless of seasonal variation by using Equations (1) and (2). The results are presented in Table 4.

$$\% \text{ Exposure reduction} = \frac{(\text{PTS} - \text{PCS or PIS})}{\text{PTS}} \times 100, \quad (1)$$

$$\% \text{ Exposure reduction} = \frac{(\text{PIS} - \text{PCS})}{\text{PIS}} \times 100, \quad (2)$$

where PTS is the overall GOM concentration of the pollutant emitted from the traditional stove during both the dry and wet seasons, PCS is the overall GOM concentration of the pollutant in clean stove taken from both the dry and wet seasons, and PIS is the overall GOM concentration of the pollutant in improved stove taken from both the dry and wet seasons.

Depending on both the type of pollutant and the aerodynamic diameter of PMs, an *Injera* baker who uses the clean stove instead of the traditional stove for baking the *Injera* can reduce his/her exposure by a minimum of 53.9% and as high as by 81.7%. Likewise, *Injera* bakers can reduce their exposure by a minimum of 12.3% and a maximum of 63.9% by using the improved stove instead of the traditional stove. Moreover, an *Injera* baker who uses the clean stove instead of the improved stove can reduce his/her exposure by a minimum of 26.5% and a maximum of 51.7%. These results are comparable with other studies conducted in Gansu Province, China, in which the improved stove has reduced the level of PM_4 by 70%, from 774 to 223 $\mu g/m^3$.[37]

Health risk assessment due to exposure of $PM_{2.5}$, PM_{10}, and TSP during baking of Injera

The health risk assessment due to the exposure to $PM_{2.5}$, PM_{10}, and TSP was carried out. Human health risk assessment due to air contaminants depends on the type of pollutants and the extent of exposure. Hazard identification, dose-response assessment, exposure assessment, and risk characterization are the major steps used in health risk assessment.[38–40] We went through each of these steps to estimate the health risk due to PMs during the baking of *Injera*. In this study, although all PMs and TVOCs are identified as hazard contaminants in the air, only $PM_{2.5}$, PM_{10}, and TSP are considered in health risk characterization due to unavailability of reference dose (RfD) values for other pollutants which are used in the calculation of hazard quotient (HQ). In the second step, ADD (average daily intake also called chronic daily intake; μg/kg/day) was calculated using Equations (3) and (4). Annual threshold values set by WHO and US EPA have used as RfD while dealing with a dose-response step; and finally, HQ was calculated in risk characterization step at different microenvironments (during the baking of *Injera* using clean, improved, and traditional stove).[38–40]

Table 5. Exposure time, exposure frequency, duration exposure, exposure duration, averaging time (AT), intake rate (IR), and body weight (BW) for adult women.

Stove type	Exposure time (h/day)	Exposure frequency (days/year)	Duration exposure (years)	Exposure duration (days)	AT (days)	IR (1/m^3/day)	BW (kg)
Clean	0.34	365	50	259	18,250	20	60.7
Improved	0.33	365	50	251	18,250	20	60.7
Traditional	0.33	365	50	251	18,250	20	60.7

Baking *Injera* is exclusively the role of women in Ethiopia. Women usually start baking around the age of 17 and may continue to do so two-to-three times a week until they are retired. Hence, only female health impacts were estimated in this study. The current life expectancy for an Ethiopian woman is around 67, of which the duration of exposure could be as high as 50 years was taken for the calculations of HQ and ADD. The exposure frequency of 365 days/year was also assumed for the calculations of HQ and ADD. The air intake rate for an adult is 20 m^3/day and body weight for adult Ethiopian women is assumed to be African adult weight, which is 60.7 kg.[41,42] The time needed for baking the *Injera* was recorded using the clean, improved, and traditional stoves while measuring PMs, and the baking was performed twice/week. Thus, 0.34, 0.33, and 0.33 h/day are used as exposure time for clean, improved, and traditional stoves, respectively. Table 5 shows the details considered in HQ calculation.

US EPA classifies the exposure as acute (exposure duration is below 2 weeks), sub-chronic exposure duration is above 2 weeks and below 7 years) and the chronic (exposure duration is above 7 years) types of exposure. The exposure duration of this study is above 2 weeks and below 7 years, it is classified under the sub-chronic type of exposure. Hence, RfD for the sub-chronic type of exposure is used, which is the annual average of $PM_{2.5}$ (10 µg/m^3), PM_{10} (20 µg/m^3), and TSP (150 µg/m^3) values set by WHO and US EPA are used to calculate HQ.[17,43] The total overall GOMs of $PM_{2.5}$, PM_{10}, and TSP regardless of the seasons have used for health risk assessments.

The following equations are used for calculating of ADD and HQ to characterize the health risk due to $PM_{2.5}$ and PM_{10}.

$$ADD = \frac{CA \times IR \times ED}{AT \times BW}, \quad (3)$$

$$ED = \frac{EF \times ET \times DE \times 1\ \text{day}}{24\ \text{h}}, \quad (4)$$

where ADD is the average daily intake (µg/kg/day); CA is the contaminates concentration in air (µg/m^3); ET is the exposure time spent (hours/day); EF is the exposure frequency (days/year); IR is the intake rate (m^3/day); ED is the exposure duration (days); DE is the duration of exposure (years); AT is the averaging time, and (AT [days] = DE [years] × 365 days/year); 1 day/24/h is the conversion factor from hours to days.

$$HQ = \frac{ADD}{RfD}, \quad (5)$$

where HQ is the hazard quotient; EC is the exposure concentration obtained from Equations (1); RfD (this converts to the same unit as ADD [µg/kg/day], that RfD expressed in µg/kg/day would be equal to the RfD in µg/m^3 multiplied by 20 m^3 air inhaled/person/day divided by 70 kg/person). It should be noted that the average weight of an African woman is assumed to be 60.7 kg. However, there is no conversion factor using the weight 60.7 kg for calculating RfD, hence 70 kg/person, the weight applied by US EPA was also in this study.

It should be noted that personal exposure monitoring involves comparison with the occupational exposure limit, the basic sampling time is 8 h for one-day (8-h) monitoring. Since the sampling duration varies significantly from, and is longer than that of working environment measurement, the method cannot always be directly applied to personal exposure monitoring. *Injera* baking is not performed continuously for 8 h. Therefore, the capability of performing continuous monitoring with a single sampler for 8 h is not always a necessary condition for exposure assessment. For this study we followed modified short-term exposure limit (STEL) for which the basic sampling duration is 15 min. In this case, an optimum sampling condition for the type of monitoring is required to be selected, that is applicable to the operation, the baking of *Injera*. Hence, we followed the method in this study was based on short-term occupational exposure limits (STV-STEL). The threshold limit value (TLV)-STEL is defined as the 15-min time weighted average (TWA) exposure concentration that shall not be exceeded, even if the 8-h TWA exposure concentration is below the TLV–TWA.[44,45]

According to US EPA, if the HQ calculated is less than one, the contaminate could not induce any health impact on the exposed organism (human), whereas its value is greater than 1 the contaminates cause or induce some health impact on the exposed human.[42] This study showed no HQ value is greater

Table 6. The ADD for PMs and TVOCs and HQs for $PM_{2.5}$, PM_{10}, and TSP for the clean, improved, and traditional stoves used for the baking of *Injera*.

ADD for PMs and TVOCs (μg/kg/day)							
ADD across stove type	PM_1	$PM_{2.5}$	PM_4	PM_7	PM_{10}	TSP	TVOCs
ADDcle	0.09	0.19	0.30	0.46	0.59	0.78	5.34
ADDimp	0.17	0.38	0.58	0.86	1.1	1.51	7.06
ADDtra	0.19	0.86	1.62	2.14	2.48	2.97	15.5
HQ for $PM_{2.5}$, PM_{10}, and TSP							
HQcle	–	0.06	–	–	0.09	0.02	–
HQimp	–	0.12	–	–	0.17	0.03	–
HQtra	–	0.26	–	–	–	0.06	–

PMs, particulate matters; TSP, total suspended particles; TVOCs, total volatile organic compounds; ADD, average daily intake; ADDcle, ADD in using clean stove; ADDimp, ADD using improved stove; ADDtra, ADD using traditional stove; HQ, hazard quotient; HQcle, HQ in using clean stove; HQimp, HQ in using improved stove; HQtra, HQ in using traditional stove.

than one in all types of pollutants and stove types, which confirmed the baking of *Injera* only could not induce any health problems. However, this does not mean that their contribution to the total chronic exposure is small. Thus, baking the *Injera* using clean, improved, and traditional stove can account for 6–38% for the permissible total chronic intake of $PM_{2.5}$, PM_{10}, and TSP. The ADD for PMs and TVOCs and HQs for $PM_{2.5}$, PM_{10}, and TSP for the clean, improved, and traditional stoves used for the baking of *Injera* are given in Table 6.

Discussion

Exposure assessment at different microenvironments is vital for estimating the risk of health impact of the exposed person and taking remedial action at an individual level. Hence, this study is the first attempt to look at the indoor air pollution during the baking of *Injera* at different microenvironments (at the clean stove, improved stove, and traditional stove). The results showed the level of PMs, and TVOCs found in decreasing order of clean stove < improved stove < traditional stove. This study has made a further contribution to demonstrate the bakers' higher degree of exposures to pollutants using biomass fuel. The study is not only for the Ethiopians but also for people living in rural parts of developing countries, which use a high amount of biomass fuels for an activity.

Furthermore, health risk assessment has been estimated for the individual type of stoves and also for the individual PMs. Despite the higher health risk associated with the biomass-based traditional stoves, a significant fraction of urban residents and the vast majority of rural people still use it for the baking of *Injera*. The continued use of traditional stove is due to many socioeconomic factors such as low-cost of the stove and biomass fuel, easy accessibility, availability of biomass fuel, and lack of alternative energy sources such as electricity. People also use the traditional stoves due to the perception that the *Injera* baked by using a traditional stove make it delicious and tasty. Therefore, policymaker should create the awareness of the health risk associated with the use of conventional stove using biomass fuel. Government should also make the improved and clean stoves readily available to the community at affordable prices.

Limitations of the study

Although this study has provided information related to the exposure level due to the PMs and TVOCs during the baking of *Injera*, it has some shortcomings. First, measuring the pollutant levels along with examining different health issues is not performed due to the limitation of professional health workers (a medical technician or nurse), which is beyond our control. However, the results of this study could be used as a benchmark for future study on the examination of different health issues caused by indoor air pollution. Second, the amount and the type of chemical substances present in the smoke of biomass fuel depend on the moisture content of the fuel, the species of plant that the fuel is originated and the amount of fuel used. The chemical constituents of the smoke also depend on the status of fire (such as smoldering and good burning status). However, this study did not go into these aspects. These shortcomings will be addressed in future work. Further work should be done on the health aspects of chronic exposure to the Ethiopian traditional baking practices along with the measurement of other pollutant levels.

Conclusion

Baking the *Injera* is a unique and the most widely practiced daily operation in Ethiopian households carried out by the women. The traditional wood burning stoves generate a considerable amount of air pollutants. The amounts of PMs and TVOCs pollutants measured in the baking of *Injera* during the wet season are relatively higher than those measured during the dry seasons using different types of stoves tested. Furthermore, the levels of TVOCs are much higher than the levels of PMs emissions from each type of stove in both the wet and dry seasons. Generally, the levels of PMs emissions found in this study using the clean stove are lower than the levels found using the traditional stoves. Thus, the *Injera* bakers (women) are subjected to lower degree of pollutants exposure when using the clean stove and hence they are less susceptible to the exposure-related health risks.

This study showed HQ value not greater than one in all types of pollutants and the stoves used, which suggests that exposure during the baking of *Injera* alone may not induce significant health problems. Although the health risk assessment due to the exposure to $PM_{2.5}$, PM_{10}, and TSP showed no health problems, its contribution to the total chronic intake is very high. Hence, the long-term consequence of these exposures to women, who do most of the *Injera* baking could be significant. Particularly, a person who uses the traditional stove for baking for a long period of time might take a higher amount PM and TVOCs. Therefore, there is need to give awareness about the health benefits of using the clean-stove instead of the traditional and improved stove.

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