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Occupational exposure to indoor air pollution among bakery workers in Ethiopia; A comparison of electric and biomass cookstoves☆

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ABSTRACT

The indoor air pollution (IAP) produced by the domestic combustion of solid fuels is responsible for up to 4 million deaths annually, especially among low and middle income countries. Occupational exposure within the food preparation industries of these nations remains underexplored. We investigated occupational exposure to the IAP produced during the commercial production of injera, a staple of the Ethiopian diet, from bakeries in Addis Ababa, Ethiopia. Measurements of $PM_{2.5}$, black carbon (via the proxy measure $PM_{2.5}$ absorbance) and CO were collected from 30 bakeries and their employees for an average of 4-h per working day. Measurements were compared between bakeries using biomass and electric cookstoves. Further, the respiratory health data of 35 bakery employees were collected by interview-based questionnaire. Personal exposure to PM2.5 from biomass cookstoves was double that of electric cookstoves (430 μg/m3 vs. 216 μg/m3), black carbon exposure was four times higher among biomass users (67 × 10-5m-1 vs. 15 × 10-5m-1), and CO exposure was twenty times higher among biomass users (22 ppm vs. 1 ppm). Mixed effect models indicated that the number of stoves in use and additional solid fuel usage (e.g. coffee brewing) also contributed to exposure levels. These findings indicate that the use of biomass powered cookstoves during commercial injera production significantly contributes to IAP and self-reported respiratory symptoms. As injera is the staple foodstuff of Ethiopia, a widespread conversion to electric cookstoves is likely to have a significant impact. However, as high levels of IAP were also observed within the electric bakeries, further identification of pollution sources is required.

1. Introduction

Approximately half the world's population relies upon the domestic combustion of solid fuels for daily heating and cooking needs (World Health Organization, 2006). Multiple lines of research have identified that the indoor air pollution (IAP – also referred to as household air pollution [HAP]) produced by this practice is responsible for up to four million deaths a year and is a significant contributor to local and global changes in climate (Gordon et al., 2014; Lacey et al., 2017). Efforts to improve access to cleaner fuels and/or improved cookstoves have played an important role in improving human health and the environment (Yip et al., 2017; Smith et al., 1717; Lan et al., 2002; Hu et al., 2014). However, occupational exposures are an underexplored aspect of this phenomenon (Hashim and Boffetta, 2014). Economic growth and local investments have resulted in increasing small and medium business in low and middle income nations. Businesses with food preparation areas (e.g. restaurants, bakeries) may use solid fuels for their food preparation, which in turn raises the risk of occupational exposure among their employees.

Within Ethiopia, the use of solid fuels for heating and cooking is widespread, a practise which significantly contributes to IAP in the residential setting (Sanbata et al., 2014). The main staple food in Ethiopia is the “injera”, a large, pancake-like bread which is eaten

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during most meals. The preparation of injera traditionally requires a specialized stove called a "mitad" which typically uses solid fuels and is part of nearly every household (Fig. 1, left image). Following increasing investments in the micro- and small scale-business sectors however, there is an ongoing shift from preparing injera at home to purchasing them from locally run bakeries of varying size and scale. Many of these mitads are powered by biomass, however recent years have seen an increasing number of bakeries using electricity powered mitads instead (Fig. 1, right image). The occupational exposure to IAP within injera bakery workers, and how that IAP is altered by the use of electric mitads, has never been evaluated.

The purpose of the current paper is to investigate and compare the IAP produced by injera bakeries within the Ethiopian capital of Addis Ababa using either biomass powered or electric mitads. As a secondary objective, this paper will also explore whether any reported symptoms of impaired respiratory health (cough, shortness of breath, etc.) are associated with the use of any particular stove type.

2. Methods

2.1. Study design and bakery selection

This paper represents a cross-sectional evaluation of the relationship between bakery type (biomass or electric) and indoor and personal measurements of IAP constituents. Bakeries were identified for potential inclusion in the study via several steps. First, municipal records were accessed to identify licensed bakeries. This initial list of bakeries identified was supplemented by following supply chains (i.e. asking stores and restaurants which bakeries supplied their stock of injera) and asking locals for locations of bakeries. This approach resulted in the identification of 77 bakeries A bakery was eligible for inclusion in this study if it sold injera to the public on a daily basis, used either biomass or electric mitads for the preparation of injera, and was willing to participate in the study. A total of 40 bakeries were willing to be visited for potential inclusion in the study, of which 30 met the full criteria for study inclusion (15 electric and 15 biomass bakeries) (Fig. 2). The biomass used was a heterogeneous combination of fuels across bakeries including wood and coffee husks. Bakeries were typically single rooms, with floor areas ranging in size from 4 to 140 m^2 (median 30m (Gordon et al., 2014)) and had a median of 3 stoves per bakery (range 1–35). A single stove would produce approximately 25 injera per hour.

Within each bakery, up to two employees were enrolled for personal monitoring of indoor pollutants. Most of the bakeries ($n = 21$) only provided one employee (11 using biomass stoves and 10 electric). Only 2 bakeries did not provide any employees for enrolment (both using biomass stoves) and 7 bakeries provided 2 employees (2 using biomass and 5 using electric stoves). Where possible, the amount of biofuel used to produce injera was weighed. Each bakery was visited twice, with visits being no more than a week apart. ANOVA testing indicated no significant variation in measurements between visits.

2.2. Measurements

Measurements of $PM_{2.5}$ (particles with an aerodynamic diameter ≤ 2.5 μm) were collected on pre-weighed 37 mm Teflon filters using an SKC cyclone with an aerodynamic cut-off of 2.5 μm connected to a BGI 400-S pump unit operating at a flow rate of 3.5 L/min. For personal measurements, pumps were placed within a backpack and the cyclone was attached near the breathing zone. For indoor measurements, the pump and cyclone were placed within the approximate centre of the bakery at a height of approximately 1.5m. It is traditional in Ethiopia to brew coffee over a solid-fuel powered stove (typically a charcoal stove) which itself

Fig. 1. Left-a traditional biomass powered cookstove (photo credit co-author Hugo van der. Zwaag) and right – an electric mitad (photo credit Energypedia, creative commons licensing (File, 2017).

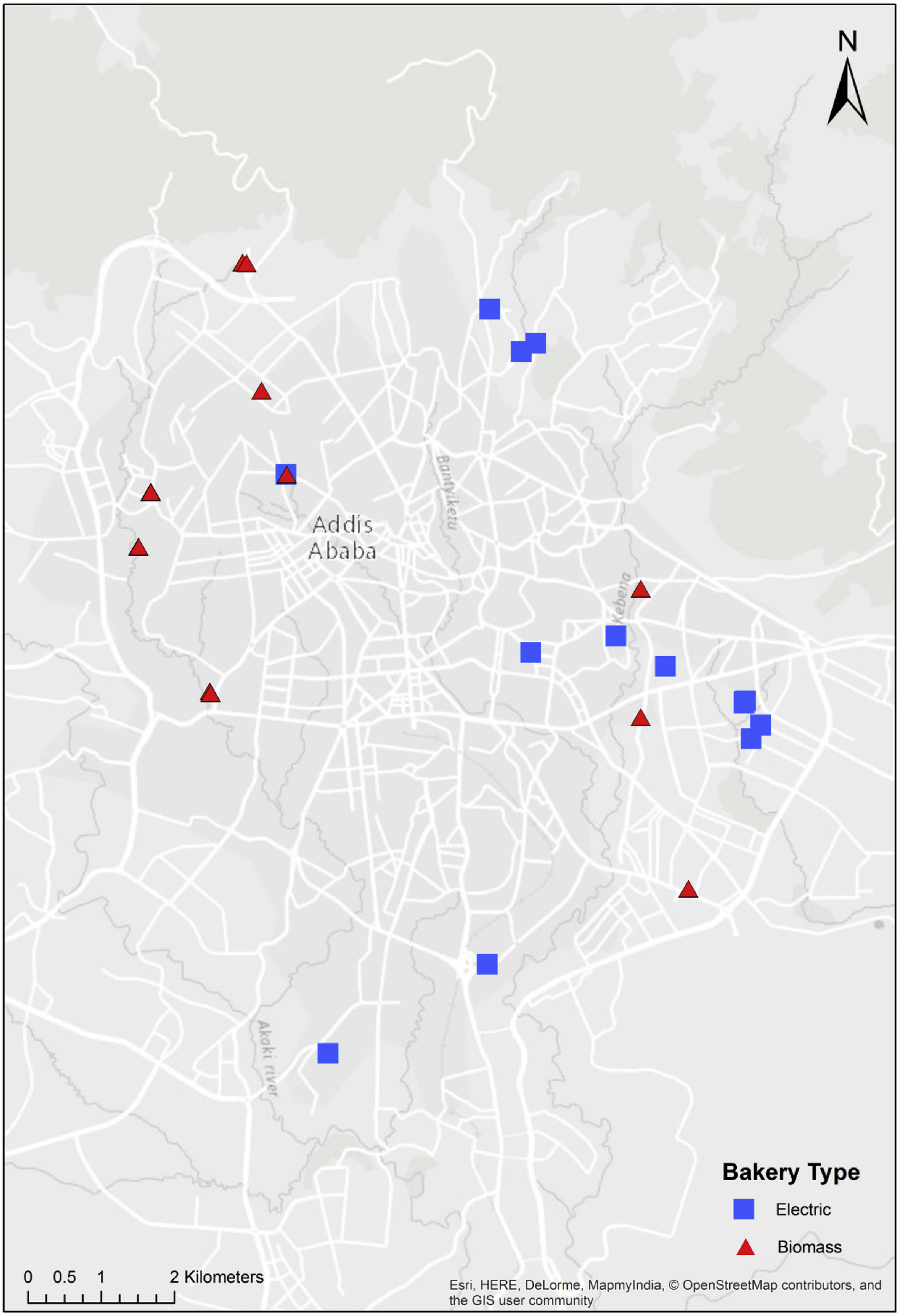

Fig. 2. Location and type of bakeries enrolled in study.

is a contributor towards IAP (Keil et al., 2010). This was recorded if it occurred during measurement collection. Outdoor measurements were collected outside of each bakery, with pumps and cyclones at a height of approximately 1.5m, directed away from any direct outdoor source of PM emission (chimneys, traffic, etc.).

Measurements were collected for an average of 4 h (range 1.5–9 h). After the collection of measurements, exposed filters were stored in individual cassettes and stored at approximately 4 °C prior to cooled transportation and subsequent measurement of particle mass (performed in the Netherlands). Particulate mass was established by pre- and post-weighing of filters in an environmentally controlled weighing room using a microbalance at 1 µg accuracy. Concentrations of $PM_{2.5}$ were calculated as a function of the measured weight divided by the volume of air drawn through the filters ($\mu g/m^3$). Approximately 6% of field measurements were collected in duplicate for quality control purposes. The average percentage difference between original and duplicate measurements was 14%.

Exposure to black carbon was measured through the common proxy of $PM_{2.5}$ absorbance, which was measured on the teflon filters collected for $PM_{2.5}$ measurements. Light reflectance was measured across five different spots on the filter using an EEL 043 Smoke Stain Reflectometer. The average value across the spots was transformed into an absorption value using the following formula (ISO. ISO, 1993):

$$a = \frac{A}{2V}\ln\left(\frac{R_0}{R_f}\right)$$

where a represents the absorption coefficient (in 10^{-5} m^{-1}), A the area of the loaded filters (0.00078 m^2), V the volume of sampled air (in m^3), R_0 the average reflectance of field blanks, and R_f the average reflectance value of the sampled filter (in percent).

Carbon monoxide (CO) exposure was measured using Gastec 1DL passive diffusion tubes in parallel with $PM_{2.5}$ measurements. After the completion of each day's measurement collection, CO measurements were read and recorded (in ppm). Tubes were stored for 24 h before a duplicate reading (performed for quality control purposes, field workers were blinded to the measurement recorded 24 h prior) was recorded (duplicate readings were identical to original readings).

2.3. Health questionnaires

All bakery employees who were enrolled for personal measurements also provided health information via a survey administered in the field. The survey included information on personal demographics, employment history, and personal health history. Respiratory symptom questions consisted of a series of yes/no questions adopted from the European Community Respiratory Health Survey (ECRHS. (Burney et al., 1994).

2.4. Statistical analysis

Normal probability plots indicated that exposures were best described using log-normal distributions. Exposure levels were summarized as arithmetic means (AM), geometric means (GM), and geometric standard deviations (GSD). Parametric testing was performed on the log-transformed exposure variables. To accommodate log-transformation, all CO levels of zero ($n = 22$) were replaced with the limit of detection (0.4 ppm) divided by square root 2 (all other samples were above the limit of detection). Indoor and personal measurements were explored further through the creation of linear mixed effect models. Individual participants and bakeries were assigned as random effects while mitad type (biomass or electric), number of mitads in operation, and presence of any additional pollution source (i.e. coffee brewing), were assigned as fixed effects. The following formula can be used to summarise the model:

$$y_{ijf} = \mu + \beta_1 x_1 + \beta_2 x_2 \ldots + \beta_n x_n + bI_i + bJ_{ij} + \varepsilon_{ijf}$$

Where: y_{ijf} represents the log-transformed value of the measurement for bakery i, person j, on day f; µ represents the intercept (i.e. “background” level); β_1 through β_n represent the fixed effect covariates for variables x_1 through x_n; bI_i represents the random effect coefficient for bakery I; bJ_{ij} represents the random effect coefficient for subject j, working in bakery i; and ε_{ijf} represents the error for bakery i, person j, on day f.

Health questionnaires were analysed by comparing survey answers between the users of different cookstoves and the development of logistic regression models to adjust responses for age, education level, and number of years employed.

All statistical testing was carried out in R version 3.03 (R Development Core Team, 2014). A p value less than 0.05 was considered to indicate statistical significance.

3. Results

3.1. Participant characteristics

A total of 35 participants provided up to 2 personal measurements each from 30 bakeries. The median number of stoves in use at each bakery was 3. Electric and biomass bakeries were similar sizes and had similar numbers of stoves in operation. Participants were exclusively female and ranged in age from 18 to 60 years (median 24). More participants (21 [60%]) were enrolled from electric bakeries and participants from biomass bakeries were generally older than those from electric bakeries (median age 30 vs. 23).

3.2. Exposure characteristics

A total of 162 samples for $PM_{2.5}$ and absorbance measurement were collected. Due to technical errors or damaged filters, 8 filters had to be discarded (2 indoor, 2 personal, and 4 outdoor samples), resulting in 58 indoor, 62 personal, and 34 outdoor samples being analysed. An overview of these measurements are presented in Table 1. Overall, the use of biomass mitads resulted consistently in higher measurements than the use of electric mitads. Personal exposure to $PM_{2.5}$ among solid fuel burning mitads (GM: 430 $\mu g/m^3$) was significantly higher than among users of electric mitads (216 $\mu g/m^3$, $p < 0.05$ via paired *t*-test). This difference extended to indoor (429 $\mu g/m^3$ vs. 148 $\mu g/m^3$, $p < 0.05$) and outdoor (72 $\mu g/m^3$ vs. 36 $\mu g/m^3$, $p < 0.05$) measurements. Indoor and personal measurements correlated highly with each other (Spearman $r = 0.76$) while indoor and outdoor measurements were moderately correlated with each other ($r = 0.50$).

Indoor measurements of $PM_{2.5}$ absorbance were significantly higher among bakeries using biomass mitads (67×10^{-5} m^{-1} for personal and 65×10^{-5} $m^{-1}$for indoor) than those using electric mitads (15 and 13×10^{-5} m^{-1}, $p < 0.05$). Outdoor measurements were also significantly higher outside biomass bakeries (23×10^{-5} m^{-1}) than outside electric bakeries (8×10^{-5} m^{-1}, $p < 0.05$). Indoor and personal $PM_{2.5}$ absorbance measurements correlated highly with each other ($r = 0.95$), as did indoor and outdoor measurements ($r = 0.80$.

Measurements of CO were significantly higher for biomass mitads (22 ppm for personal and 18 ppm for indoor) than electric

Table 1
Summary values for measured pollutants.

	Stove type	Personal				Indoor				Outdoor[a]			
		N	AM	GM	GSD	N	AM	GM	GSD	N	AM	GM	GSD
$PM_{2.5}$ (μg/m^3)	Biomass	28	540	430	2.0	29	624	429	2.3	17	76	72	1.4
	Electric	34	299	216[b]	2.2	29	199	148[b]	2.3	17	50	36[b]	2.7
$PM_{2.5}$ Absorbance (10^{-5}m^{-1})	Biomass	28	79	67	1.9	29	72	65	1.8	17	25	23	1.5
	Electric	33	17	15[b]	1.8	29	16	13[b]	2.0	17	11	8[b]	3.7
CO (ppm)	Biomass	22	29	22	2.4	22	27	18	3.0	9	6	2	5.2
	Electric	22	4	1[b]	5.0	18	4	2[b]	4.2	11	3	1	4.0

[a] Outdoor measurements were collected outside bakeries during indoor measurement collection. Samplers were directed away from direct sources of pollution (chimneys, traffic, etc.).

[b] $p < 0.05$ via *t*-test; parametric testing was performed on the log-transformed exposure variables.

mitads (1 and 2 ppm respectively, $p < 0.05$). Measurements collected from outside bakeries using biomass mitads (2 ppm) were slightly higher than those outside bakeries using electric mitads (1 ppm), however this difference did not reach statistical significance. Indoor and personal CO measurements correlated highly with each other ($r = 0.94$), while indoor and outdoor measurements were more moderately correlated ($r = 0.63$).

3.3. *Mixed effect models*

Linear mixed effect models were developed to identify the effect that fuel type, additional pollution source, and number of mitads in operation had upon measurements of $PM_{2.5}$, $PM_{2.5}$ absorbance, and CO (Table 2). Similar to the descriptive analysis, the use of a biomass mitad was found to result in higher personal and indoor measurements to all measured pollutants than the use of electric mitads (geometric mean ratio [GMR]: 2.85, 5.11, and 18.53 for personal exposure to $PM_{2.5}$, $PM_{2.5}$ absorbance, and CO respectively). The presence of an additional pollution source was also found to result in higher measurements of all pollutants (GMR: 1.87, 1.11, and 5.37 for personal exposure to $PM_{2.5}$, $PM_{2.5}$ absorbance, and CO respectively). The number of mitads in use at a time was found to only be positively associated with personal measurements of $PM_{2.5}$ (GMR 1.04 per increase of one stove).

3.4. *Self-reported health*

All 35 women who participated in the collection of personal measurements completed the health surveys. Overall, there was very little contrast among study participants regarding self-reported health. All participants were non-smokers. None of the study participants reported histories of asthma, pneumonia, nasal allergies (including hay fever), or persistent phlegm production. Positive histories of tuberculosis were reported for two participants (one from a biomass bakery and another from an electric bakery), both of which occurred several years ago. One participant (who worked at an electric bakery) reported a cough and wheeze on most days. All but one participant (a worker at a biomass bakery) reported at least one episode of rhinitis in the past 12 months. A history of eczema within the past 12 months was reported by one participant (worked at an electric bakery).

A total of 13 participants answered yes to the question "Do you have to stop for breath when walking at your own pace on level ground (8[57]% of biomass workers and 5[24%] of the electric bakery workers). Personal exposure to measured pollutants, aggregated across all measurements, was higher among those who answered yes than those who answered no (316 μg/m^3, 31×10^{-5} m^{-1}, and 8 ppm for $PM_{2.5}$, absorbance, and CO respectively vs. 262 μg/m^3, 25×10^{-5} m^{-1}, and 5 ppm).

Table 2
Linear mixed effect modelling of ln-transformed measurements.

	Personal								
	$PM_{2.5}$			$PM_{2.5}$ absorbance			Carbon Monoxide		
	Estimate	95% CI	GMR	Estimate	95% CI	GMR	Estimate	95% CI	GMR
Bakery type									
Electric	Ref		1	Ref		1	Ref		1
Biomass	1.05	0.6,1.5	2.86	1.63	1.20,2.07	12.35	2.92	2.33,3.51	18.53
Other pollution source[b]									
No	Ref		1	Ref		1	Ref		1
Yes	0.63	0.23,1.01	1.87	0.1	−0.26,0.47	5.11	1.68	1.09,2.27	5.37
Number of stoves in bakery	0.04	0.01,0.07	1.04	0.01	−0.03,0.04	1.11	−0.03	−0.06,0.00	0.97
Intercept/Reference value[a]		4.71			2.51			−0.21	
	Indoor								
Bakery type									
Electric	Ref		1	Ref		1	Ref		1
Biomass	1.32	0.78,5.07	3.74	1.71	1.31,2.11	5.56	2.46	1.76,3.14	11.72
Other pollution source[b]									
No	Ref		1	Ref		1	Ref		1
Yes	0.71	0.35,1.07	2.03	0.36	0.04,0.67	1.43	1.52	0.82,2.18	4.57
Number of stoves in bakery	0.004	−0.04,0.05	1.00	0.01	−0.02,0.04	1.01	−0.04	−0.09,0.01	0.96
Intercept/Reference value[a]		4.57			2.33			0.12	

GMR = geometric mean ratio = GM(estimate)/GM(reference) = exp(Estimate).

[a] Reference value represents log-transformed exposure value for reference model entry (electric stove with no other pollution source and a theoretical "zero" stoves in the bakery).

[b] Refers to additional pollution source (e.g. coffee brewing on solid fuel) within the bakery.

The relationship between self-reported stopping for breath and employment location was further analysed via logistic regression adjusted for age, education level and number of years employed at the bakery. Workers at biomass bakeries had 6.9 (95%CI: 1.3 to 52.8) times the odds of reporting stopping for breath than workers at electric bakeries (Table 3).

4. Discussion

Indoor air pollution (IAP), produced by the domestic combustion of solid fuels, is a significant cause of morbidity and mortality across the world – especially in low and middle income countries (World Health Organization, 2006). Within these countries, economic development has provided new opportunities for social and economic advancement, including the growth of local business. However, within the food preparation industry, the ongoing use of solid fuels means that these economic opportunities may come at the cost of workers' health. Within Addis Ababa, Ethiopia, the preparation of the staple food “injera” is transitioning from being prepared at home to being produced by a series of locally owned and operated bakeries. The stoves used by these bakeries are traditionally heated by biomass, although an increasing number of them are electrically powered. The current study has compared the IAP produced and self-reported health of employees within injera bakeries utilizing one of these two stove designs.

We have found that bakeries utilizing electric stoves had significantly lower levels of $PM_{2.5}$, black carbon, and CO than those using biomass stoves. Also identified as drivers of IAP were the presence of additional pollution sources (e.g. coffee brewing) and (in the case of $PM_{2.5}$) the number of stoves in use. The measurements reported in the current paper have implications for both personal and environmental health. Values of $PM_{2.5}$ and CO are well in excess of those stipulated by air quality guidelines (World Health Organization; WHO, 2014) and black carbon, through heat absorption and reduced albedo, is an important driver of climate change (Anenberg et al., 2012; Schmidt, 2011). We note, that even within the electric-stove bakeries, exposures to $PM_{2.5}$ were substantially higher than WHO limits. This may in part be driven by additional indoor sources of $PM_{2.5}$. For example, coffee in Ethiopia is traditionally brewed over a solid-fuel powered stove which itself is a contributor towards IAP (Keil et al., 2010). This activity was frequently observed during data collection, and was found to contribute to measurement levels during mixed effect model construction. Further, the act of food preparation itself contributes to IAP (as food particles become airborne during the preparation process). However, as the bakeries were all a similar operating size, these contributions are likely to be consistent across bakeries using both biomass and electric mitads, meaning that we would not expect these sources to bias our findings in a single direction.

Solid fuels are widely used within Ethiopia for domestic cooking and heating, and previous exposure studies have identified IAP levels associated with the domestic use of solid fuels similar to those reported here (Sanbata et al., 2014). Therefore, exposures experienced in the home may be similar to those experienced during work hours making it difficult to explicitly state which health effects of chronic IAP exposure could be attributed to occupational exposure and which to domestic exposure. However, given the clear improvement in air quality observed within the bakeries employing electric mitads, we can speculate that the use of electric mitads would result in some health gains. This is reflected in the exploratory health survey where (aggregated) exposures were higher among people who reported having to stop for breath while walking. Further, biomass mitad workers were 7 times more likely to report shortness of breath than electric stove workers. These findings are consistent with other research where improvements in both self-reported health and long-term health have been reported in relation to stove improvements. For example Diaz et al. reported, in a study of women in rural Guatemala, that 52.8% of study participants who received an improved cookstove reported an improvement in their health (compared to 23.8% of the participants who did not receive an improved stove) (Diaz et al., 2008). Further, Chapman et al. reported a risk ratio of 0.58 for the development of COPD among non-smoking Chinese women following the implementation of improved cookstoves (Chapman et al., 2005). We note that within our analysis, we report very wide confidence intervals on this analysis, which is a representation of the small sample size. It should also be noted that other respiratory outcomes (cough, phlegm, wheeze etc.) did not receive a positive response from study participants and that medical examinations were not available for the study population. The health survey should be considered a pilot study, which needs to be confirmed and extended in future epidemiological studies.

An additional consideration is that of ante-natal and childhood exposure. Every person encountered preparing injera was female and it was commonly observed that children would accompany their mothers to their places of work. The World Health Organization estimates that up to 50% of the premature deaths among children can be attributed to IAP exposure and solid fuel use is responsible for at least half a million childhood deaths per year globally (WHO, 2017a; WHO, 2017b). Further, exposures to IAP during pregnancy has been associated with increased risks of pre-eclampsia, reduced birth weight, and increased risks of still-birth (Agrawal and Yamamoto, 2014; Wylie et al., 2014; Amegah et al., 2014). Therefore, in addition to worker health, a reduction in the IAP produced in injera production may also have an impact upon childhood and ante-natal health.

In addition to health effects, the combustion of solid fuels is a significant contributor towards global warming and environmental damage. Black carbon operates as a short-term driver of global climate change through its ability to absorb heat and reflect sunlight (Schmidt, 2011; Martin et al., 2014; Chung et al., 2005). The levels of black carbon reported within the current paper are in

Table 3
Self reported health among study participants.

	Electric bakery, n (%)	Biomass bakery, n (%)	OR (95% CI), unadjusted	OR (95% CI), adjusted [a]
Stop for breath	5 (24%)	8 (57%)	4.3 (1.0,19.8)	6.9 (1.3,52.8)
Cough	1 (5%)	0	–	–
Phlegm	0	0	–	–
Wheeze	1 (5%)	0	–	–
History of asthma	0	0	–	–
History of Tuberculosis	1 (5%)	1 (7%)	–	–
History of pneumonia	0	0	–	–
Nasal allergies/hay fever	0	0	–	–
History of rhinitis	21 (100%)	13 (93%)	–	–
History of eczema	0	0	–	–

[a] Adjusted for age, education level, and number of years employed at the bakery.

excess of those typically reported in both high-income and low-middle-income countries (Downward et al., 2015; Durant et al., 2014; Eeftens et al., 2012). Applying Quincey, 2007 (Quincey, 2007) to estimate concentrations of black carbon from absorbance measurements provides additional insight. The median estimated personal exposure to black carbon concentration within the study population is 32 μg/m^3 (biomass bakeries: 91 μg/m^3, electric bakeries: 18 μg/m^3). These levels are well in excess of similar settings including biomass users in Ghana (9 μ/m^3) and rural China (up to 18 μg/m^3) (Downward et al., 2015; Van Vliet et al., 2013; Baumgartner et al., 2014; Shan et al., 2014). Therefore, the production of injera using biomass powered mitads represents a potentially significant contributor to short-term climate change. Further, the unsustainable harvesting of wood for fuel contributes to deforestation, further damaging the local environment. A bakery operating 3 wood stoves (the median bakery size in the current study) would produce approximately 600 injeras in an 8 h working day. Based on our field findings, 1.4 kg of fuel would be sufficient to produce 3 injeras. Therefore, 280 kg of fuel per day and over 70 tons of fuel per year would be consumed by a single bakery. These calculations, while crude, indicate that the environmental impact of such a fuel demand is clear. Alternatively, electricity production in Ethiopia is largely (over 95%) produced by renewable sources (wind and hydropower), both of which have relatively low impacts upon climate (International Energy Agency, 2008; Varun and Prakash, 2009; Sims et al., 2003). Therefore, in addition to the health gains already described, there is a clear environmental benefit to be gained from the wide-spread adoption of electric mitads. However, before any such changes can be fully implemented, care needs to be taken to ensure that sufficient infrastructure exists to meet this demand. Intermittent power-cuts and “brown-outs” are anecdotally common place in Addis Ababa (Teshome, 2015), thus improvements to infrastructure would likely be required prior to a full-scale replacement of mitads.

While this study is the first that we are aware of to investigate solid fuel use and IAP exposure within the food preparation industry, there are several limitations which must be considered. First, the small sample size means that, although statistically significant results have been observed, some imprecision in findings remains (as observed with the wide confidence intervals for the ORs produced in Table 3). Despite efforts to document the types and amounts of solid fuels used within bakeries, we were unable to identify a unified solid fuel (e.g. stoves only burning wood, or coffee husks), instead we were required to classify stoves as being biomass or electricity powered. A further limitation of the current study is that, owing to practical limitations, there was a wide range of measurement times for the collection of data (range 1.5–9 h, mean 4 h). However, the average measurement time for both biomass and electric bakeries was equivalent (4 h), suggesting that any error introduced by this variation in measurement time would be non-differential. Additionally, this research was undertaken in the capital city of Ethiopia, which is a large urban centre. Smaller cities and rural environments in Ethiopia lacking the same level of infrastructure may have less well maintained stoves, meaning that we may be under-estimating exposures for these settings. Further, the preparation of injera is somewhat specialized to Ethiopia, therefore the generalizability of findings from this study to other food preparation industries (even those using solid fuels) will be limited. Health surveys were limited in that they relied solely on self-reported data and that no clinical testing or examination was performed to provide a more detailed overview of health status.

5. Conclusion

This study has investigated PM$_{2.5}$, black carbon, and CO inside injera bakeries in Addis Ababa, Ethiopia. The use of biomass cookstoves has resulted in significantly higher levels of pollution being measured, which will likely have significant impacts upon both human health and the environment, as observed by self-reported data. Pollution levels, while lower in electric mitads using bakeries, remains high. Further studies, investigating additional pollution sources and the specific health effects associated with the stoves used will be required to better understand the role that occupational exposure plays within this population.

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Declaration of conflicting interests

Co-author L. Simons is a member of Magic Ventures B·V. who are developing a fuel efficient electric mitad for the Ethiopian market and provided assistance during data collection. The product in development by Magic Ventures B·V was not evaluated as a part of this publication, however participating bakeries were offered the opportunity to test their product.

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