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Exposure to Household Air Pollution from Biomass-Burning Cookstoves and HbA1c and Diabetic Status among Honduran Women

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Abstract

Household air pollution from biomass cookstoves is estimated to be responsible for more than two and a half million premature deaths annually, primarily in low and middle-income countries where cardiometabolic disorders, such as Type II Diabetes, are increasing. Growing evidence supports a link between ambient air pollution and diabetes, but evidence for household air pollution is limited. This cross-sectional study of 142 women (72 with traditional stoves and 70 with cleaner-burning *Justa* stoves) in rural Honduras evaluated the association of exposure to household air pollution (stove type, 24-hour average kitchen and personal fine particulate matter [$PM_{2.5}$] mass and black carbon) with glycated hemoglobin (HbA1c) levels and diabetic status based on HbA1c levels. The prevalence ratio [PR] per interquartile range increase in pollution concentration indicated higher prevalence of prediabetes/diabetes (versus normal HbA1c) for all pollutant measures (e.g., PR per 84 $\mu g/m^3$ increase in personal $PM_{2.5}$, 1.49; 95% confidence interval [CI], 1.11 – 2.01). Results for HbA1c as a continuous variable were generally in the hypothesized direction. These results provide some evidence linking household air pollution with the prevalence of prediabetes/diabetes, and, if confirmed, suggest that the global public health impact of household air pollution may be broader than currently estimated.

Key Words: indoor air pollution, biomass cookstoves, Diabetes Type II, HbA1c, cross-sectional study, developing countries

Practical Implications: We report evidence supporting an association between exposure to household air pollution and prevalent prediabetic/diabetic status that is consistent with growing evidence for an association from ambient air pollution studies. Ambient air pollution studies have primarily evaluated lower air pollution levels in high-income countries; we have examined this association in a low-income country where cardiometabolic diseases are rising rapidly. These results may have important implications regarding the impact of household air pollution on the global burden of disease, which currently does not include diabetes in the estimates for household air pollution due to lack of evidence.

Introduction

More than 40% of the world's population, mainly in low and middle-income countries, relies on solid fuels for daily cooking activities.[1] Household air pollution resulting from cooking with solid fuels is the top environmental risk factor for the global burden of disease; estimated in 2016 to be responsible for more than two and a half million premature deaths and 77 million disability adjusted life years annually.[2] Only a limited number of health outcomes (lower respiratory infections, cataract, ischemic stroke, hemorrhagic stroke, ischemic heart disease, chronic obstructive pulmonary disease, tracheal, bronchial, and lung cancer) were included in the 2016 global burden estimates, making the full scope of the burden of disease attributed to household air pollution uncertain.

Metabolic conditions related to cardiovascular disease, such as Type II diabetes, are increasing in prevalence in many low- and middle-income countries but were not included in the burden of disease estimates for household air pollution.[3,4] Evidence of the association of air pollution with diabetes or HbA1c is growing but comes mainly from studies in higher income countries that evaluated ambient air pollution.[5,6] Only one previous study evaluated household air pollution and diabetes, reporting an increased odds of prevalent diabetes (OR, 2.48; 95% CI, 1.59 to 3.86) in self-reported solid fuel users compared to non-users in China.[7] This study did not measure exposure directly but evaluated the self-reported use of solid fuels (yes/no) as a proxy for exposure to household air pollution.

We performed a cross-sectional study evaluating associations of exposure to household air pollution (stove type and quantitative kitchen and personal pollution concentrations) with glycated hemoglobin (HbA1c; an indicator of average plasma glucose concentration over the past three months used to diagnose diabetes[8]) and with the prevalence of prediabetes/diabetes in households in rural Honduras using traditional and cleaner-burning *Justa* stove models. We additionally evaluated interaction by age. To our knowledge this is the first study to examine the association of household air pollution with this indicator of blood sugar incorporating quantitative air pollution measurements.

Data and Methods

Study population

We obtained exposure and health measurements from 150 women in 11 rural communities near La Esperanza in western Honduras between February and April 2015. The study participants represented a convenience sample selected from a pool of more than 500 households that had been screened in a household survey three months earlier. Eligible participants had to be the primary cook in their household, between 25 and 56 years of age, non-smokers, not pregnant and using either a traditional cookstove or a *Justa* cookstove as their primary stove. If they had a *Justa* cookstove they had to have owned it for at least four months prior to study enrollment. Traditional stoves were self-built stoves with a large open combustion chamber, either elevated or on the ground (Figure 1). *Justa* stoves had been installed according to fixed guidelines with an elevated, insulated combustion chamber, a chimney, a griddle, and a soot collector that allows for removal of excess ash from the chimney. Eight women were excluded due to missing HbA1c data. The study protocol was approved by the Colorado State University Institutional Review Board. Informed consent was obtained from all participants.

Exposure to Household Air Pollution

Particles less than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) were collected on 37mm Teflon-coated glass fiber filters (Fiberfilm™ T60A20, Pall Corporation, Port Washington NY, USA) using AirChek XR5000 pumps (SKC Inc., Eighty Four, PA, USA) and Triplex Cyclones (BGI by Mesa Labs, Butler NJ, USA) operating at 1.5 L/min and analyzed gravimetrically to determine $PM_{2.5}$ mass. All kitchen and personal air pollution measurements were collected over 24 hours. For kitchen measurements, monitors were placed at a distance of 76-127 cm from the stove edge. For personal measurements, monitors were worn by the woman attached to a bag strap to measure the air near her breathing zone.

The pumps were pre-calibrated to 1.5 L/min and post-checked using a DryCal Dc-Lite primary flow meter (Bios International Corporation, Butler NJ, USA) to ensure that the flow rate did not deviate by more than 10%. Quantitative pollution measurements were missing in 41 houses (n=12 traditional stoves and n=29 *Justa* stoves). For $PM_{2.5}$ concentrations, a 24 hour time-weighted average was calculated by dividing the filter mass (post-sampling filter weight minus pre-sampling filter weight) after blank correction by the sampled volume (average volumetric flow rate times sample duration). The limit of detection (LOD, 54 µg) was calculated by adding the mean mass of the measurement blanks (29 µg; n=7) to a value representing three times the standard deviation of the measurement blanks (8 µg).[9] Concentrations below the limit of detection (ambient: n=7; personal: n=4) were substituted by LOD/(square root of 2).

$PM_{2.5}$ black carbon concentrations were based on the optical transmission of light through the air sampling filters using a transmissometer (model OT-21, Magee Scientific, USA). Transmission data were converted to mass concentrations based on published mass-absorption values for combustion aerosol and corrected for a filter loading artifact that leads to an underestimation of the black carbon concentration at high sample loading.[10,11] The LOD was estimated to be 0.86 µg/m³ corresponding to three times the standard deviation of 54 blank samples (additional blank filters were used from field sampling campaigns conducted within the same year to estimate the reference values for the transmissometer since pre-sampling transmission data were not collected on sample filters). Values below the LOD (ambient: n=3; personal: n=10) were substituted by LOD/(square root of 2). More detailed information on black carbon methods is available as supplementary materials.

As an additional indicator of exposure to household air pollution we evaluated a dichotomous stove type variable (traditional vs. *Justa* stoves).

Health Endpoints

Participants were not required to fast for the health measurements. Glycated hemoglobin (HbA1c) was measured with the A1CNow+® system (PTS Diagnostics, Indianapolis, USA) using a finger stick sample of 5μl of blood, collected with BD Genie™ lancets (BD, Franklin Lakes, USA). Prediabetes was defined as having HbA1c ≥5.7% and ≤6.4%, and diabetes was defined as having HbA1c >6.4%;[12] due to a limited number of participants with diabetes based on the HbA1c levels (n=3) we combined prediabetes and diabetes into one category.

Additional Information

We evaluated several measures of socioeconomic status. Beds per person in the household were calculated by dividing the total number of beds by the number of people living in the house. Years of school completed was dichotomized as less than six years and six years or greater than six years, which is the required number of school years in Honduras. The presence of electricity in the house was assessed (yes/no). A material assets variable was defined by the number of the following items the household possessed: cars, bikes, motorbikes, televisions, radios, refrigerators, sewing machines, electricity.

A dietary diversity score representing the last 24 hours of food consumption was created by adding up the number of consumed food groups.[13] A list of 19 individual food items was condensed into 10 food groups (cereals, pulses and nuts, roots, other vegetables, fruits, sugar/sweets, eggs, dairy, meat, and beverages). The dietary diversity score is sometimes used in place of socioeconomic status as it often varies according to socioeconomic status.[14] Salt, sugar and fat intake were ascertained by showing the women commonly purchased quantities of the specific items and asking how often the amounts were purchased. Average daily intake for each item was estimated by dividing the total daily household intake by the number of household members.

Physical activity was assessed by asking women how many hours per day and how many days per week they perform culturally typical activities. For each activity the number of hours per week was estimated and multiplied by the corresponding metabolic equivalent (MET) from a compendium of physical activities and added up to estimate weekly METs.[15]

Waist circumference was measured around the smallest circumference of the natural waist of the woman or if this was not obvious at the upper border of the belly button. Weight was measured with a scale. Height was taken with a tape measure with the woman standing with her heels against a wall. Body mass index (BMI) was calculated by dividing the height in meters by the squared weight in kilograms. Hip circumference was measured around the broadest part of the woman's hips. The waist-to-hip ratio was calculated by dividing the waist circumference by the hip circumference.

Caffeine intake on the same day prior to the health measurements (yes/no) and the number of years the woman had been cooking were assessed by questionnaire. Elevation of the house was measured using the cell phone app maps.me (My.com B.V. version 6.5.3). Mean kitchen temperature was assessed with the EL-USB-2 Data Logger (Lascar Electronics, Erie, PA).

Data Analysis

Data were analyzed using Stata 13.1 (StataCorp LP, College Station, TX) and R version 1.1.383 (R foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were calculated for exposure and health outcomes as well as for potential confounders. A potential outlier of HbA1c (13%) was excluded from primary HbA1c analyses. Box-plots were created for pollutant concentrations by stove type. Spearman correlation coefficients were calculated between different pollution measurements. Linear regression models were fitted and adjusted for potential confounders to evaluate continuous HbA1c. To evaluate diabetic/prediabetic vs. normal status, adjusted Poisson (as recommended by Barros et al.[16]) and logistic regression models were used to estimate prevalence ratios and odds ratios, respectively. For the linear regression models the continuous pollution values were log-transformed to satisfy the assumptions of the model; the pollution variables were not transformed in the Poisson and logistic regression models as this was not needed to meet the assumptions of the models.

Linear models included age (continuous), dietary diversity score (continuous), beds per person (continuous), BMI (continuous) and physical activity (continuous) based on previous literature. Poisson and logistic models included age (continuous), dietary diversity score (continuous), and years of school (binary) after evaluating model parsimony and adding BMI and physical activity did not make any meaningful difference. Results of Poisson and logistic regression models are presented per interquartile range (IQR) increase in 24-hour average pollution concentration or in relation to a reference category for stove type (reference = *Justa* stove). Results of linear regression models are presented per one unit increase of log-transformed exposure or in relation to a reference category for stove type (reference = *Justa* stove).

For HbA1c, additive interaction was assessed in linear regression models by including terms multiplying log-transformed pollution or stove type and a dichotomous age variable (using the median value of 40 years). In Poisson and logistic regression models, multiplicative interaction was assessed using terms created by multiplying the pollution or stove type variable of interest with age.

In sensitivity analyses we evaluated additional potential confounders (substituting alternative measures of socioeconomic status [years of school, beds per person, electricity status, number of assets], diet [daily sugar, fat or salt intake], and an anthropometric measure of obesity [BMI, waist circumference, or waist-to-hip ratio]) by evaluating if there were any meaningful changes in the effect estimates of interest. We also evaluated additional potential confounders by adding elevation, mean kitchen temperature, recent caffeine intake, and the number of years the woman had been cooking. In additional sensitivity analyses we added back the participant with an unusual HbA1c value, removed one participant who had a self-reported diabetes diagnosis, removed participants who reported occasional exposure to secondhand smoke (n=5), removed participants with a BMI<18.5 (n=5), and included a term for community (to account for potential non-independence of responses within community). We also removed participants whose $PM_{2.5}$ pump flow had decreased by more than 10% during the 24-hour measurement (kitchen: n=3, personal: n=5).

Results

Our study population consisted of 142 women with a mean age of 37.5 years (standard deviation [SD], 9.0; range, 25-56 years). There were no meaningful differences in age, BMI, socioeconomic status, dietary diversity score or self-reported physical activity between traditional and *Justa* stove users (Table 1). All four air pollution measurements (kitchen and personal $PM_{2.5}$ and black carbon) were on average higher for participants with traditional stoves than those with *Justa* stoves (Table 2). Kitchen and personal $PM_{2.5}$ concentrations were on average 62% and 48% lower, respectively, in *Justa* stove users than in traditional stove users; results for black carbon were similar. However, there was substantial overlap between groups (Figure 2; Table 2). Air pollution measurements were highly correlated (between and within kitchen and personal measurements; Spearman correlation coefficients ranged from 0.67 – 0.89).

Prediabetes/Diabetes

Nearly a third (n=46; 32%) of participants were prediabetic (n=43; 30%) or diabetic (n=3; 2%) based on their HbA1c levels; one woman with a normal HbA1c level reported being diagnosed with diabetes by a doctor.

After adjusting for age, dietary diversity score and years of school, the estimated PR of prevalent prediabetes/diabetes was 1.49 (95% CI, 1.11 - 2.01; n=101) per interquartile range increase in 24-hour average personal $PM_{2.5}$ (IQR=84 $\mu g/m^3$) (Table 3). Kitchen $PM_{2.5}$ and kitchen and personal black carbon had similar results (Table 3; crude and adjusted results in Supplementary Table 1). Results by stove type were not consistent. Crude and adjusted ORs from logistic regression were in the same direction as and stronger than the PRs (Supplementary Table 2). We observed limited evidence of synergistic multiplicative interaction between age and both kitchen and personal black carbon using Poisson regression; the effects of kitchen black carbon on prediabetes/diabetes was stronger among women ≥40 years of age compared to women <40 years (p for multiplicative interaction = 0.50; Supplementary Table 3). Interaction results from logistic regression are given in Supplementary 4.

HbA1c

Average HbA1c levels in the study population were 5.50% (SD, 0.40; range, 4.1-6.5%; n=141) (Table 1). Adjusting for age (continuous), dietary diversity score (continuo), beds per person (continuous), BMI (continuous), and physical activity (continuous), the mean difference in HbA1c per 1 unit increase in log-transformed kitchen $PM_{2.5}$ mass was 0.028% (95% CI, -0.029 - 0.086; n=103; Table 4). Results for other pollution metrics were similar (Table 4; crude and adjusted results are presented in Supplementary Table 5). Results for stove type were consistent with a null association (Table 4). The effect of personal black carbon on HbA1c levels was greater among women ≥40 years of age compared to women <40 years (p for additive interaction=0.05; Supplementary Table 6). Similar results were observed for kitchen black carbon (p for additive interaction=0.29, Supplementary Table 6).

Sensitivity Analysis

When evaluating the robustness of our results in sensitivity analyses we did not observe any meaningful impact on the results for any of the sensitivity analyses described (results not presented).

Discussion

In the present cross-sectional study among 142 women in Honduras, we observed a higher prevalence of prediabetes/diabetes in women with higher exposure to household air pollution and suggestive evidence of a stronger effect in women ≥40 years of age. Considering HbA1c on a continuous scale, results were consistent with a null association, but estimates were generally in the hypothesized direction and consistent with results for prevalent diabetic status.

Although we observed lower average levels of all air pollution metrics in *Justa* users than in traditional stove users and relatively low concentrations for a biomass stove, average $PM_{2.5}$ values were still higher than the annual interim target-1 (35 μg/m^3) from the WHO guidelines.[17] Nevertheless, we observed evidence of associations between air pollution measurements and health outcomes even within this range of pollutant concentrations. The overlap in exposure between traditional and *Justa* stoves is large and may explain why we do not observe an effect by stove type although there is a shift in distribution in lower concentrations observed among the *Justa* stoves.

To our knowledge this is the first study to evaluate the association between quantitative measures of household air pollution from biomass cookstoves and prevalence of diabetes. Our results regarding prediabetes/diabetes are consistent with several previous studies on air pollution and diabetes, although these were mostly performed in high-income countries evaluating ambient air pollution.[18,19] A cross-sectional study in China observed an elevated prevalence ratio=1.14 for diabetes as well as a positive association with HbA1c (a mean increase of 0.08%; 95% CI, 0.06 -

0.10) per IQR increase in ambient $PM_{2.5}$ (41.1 μg/m^3).[20] Other studies evaluating PM_{10} in ambient air have also reported a positive association between air pollution and diabetes.[21-23] We use PRs from Poisson regression and ORs from logistic regression to report our results on prediabetes/diabetes prevalence as both methods have been used when analyzing and interpreting binary outcomes from cross-sectional data. The PR is a conservative measure and may be easier to interpret, while the OR may overestimate associations, particularly when the outcome is not rare, but has been more widely used in previous studies and therefore allows for greater comparability.[24,25]

The only previous study evaluating household air pollution and diabetes utilized self-reported use of solid fuels and diabetes prevalence in China.[7] The authors reported an increased odds of prevalent diabetes in solid fuel users compared to non-users (OR, 2.48; 95% CI, 1.59 - 3.86), a result that is consistent with our findings for directly measured pollution levels (OR per IQR increase in kitchen $PM_{2.5}$, 1.83; 95% CI, 1.11 – 3.02); our results for stove type were not consistent with these results. However, our stove type categories may have less contrast as we did not include users of other fuels but distinguished between biomass users using different stove models.

Our analyses provided suggestive evidence that the effects of some household pollutants on diabetes are stronger among women ≥40 years of age compared to women <40 years. These observations support the findings of the previously mentioned Chinese study that reported evidence of interaction between age and solid fuel use for prevalent diabetes.[7] Supportive evidence that older women may experience stronger associations with household air pollution on cardiometabolic endpoints has also been observed with blood pressure.[26-28]

Evaluating diabetes is of particular interest in this setting as the International Diabetes Federation estimates that by 2040 the number of people with diabetes will increase by 65% in South and Central America.[29] Nearly 30% of our study population was considered prediabetic, but only three participants (2.1%) were in the diabetic range based on HbA1c levels. The prevalence of diabetes in our study population was low compared to the 7.9% reported in the average Honduran female adult population (20-79 years) from the WHO country profile;[30] this difference may be due to our younger population. Estimates from the WHO country profile are based on a short-term blood glucose test commonly used in health centers, which is only reliable when taken in the fasting status.[8] If participants were non-fasting for the WHO estimates, diabetes prevalence may have been overestimated. The HbA1c measurement we applied yields more long-term information on blood glucose over the previous three months.[8] HbA1c is also considered a better predictor of blood lipid profile than fasting blood glucose with which it moderately correlates.[31] Previous human and animal studies have evaluated several pathways on how air pollutants and $PM_{2.5}$ in particular can promote the development of diabetes.[32,33] Proposed mechanisms include insulin resistance and visceral inflammation,[34] oxidative stress in brown adipose tissue,[35] endoplasmic reticulum stress as well as brown adipose tissue and endothelial dysfunction.[32,36,37]

In addition to the potentially limited sample size, the following factors should be considered when interpreting our results. Selection bias may have occurred when recruiting the convenience sample; however, it is unlikely that selection/participation was influenced by both exposure and disease status. Given the cross-sectional design, we were not able to establish temporality between exposure and the health effects examined; however, stove use in these populations is typically stable over time, and by design the *Justa* users had owned the stove for at least four months, with a mean of 24 months (range, 4–120 months). Only three out of 46 participants (6.5%) that we classified as prediabetic/diabetic were diabetic (the rest were prediabetic), potentially limiting the applicability of our results to diabetes. An evaluation of different point of care devices to measure HbA1c reported that the device we used is prone to a negative mean bias (i.e., consistently measures a lower value for HbA1c compared to the standard) resulting in low sensitivity and high specificity for prediabetes/ diabetes classification. Therefore, the measurement error for prediabetes/diabetes classification would likely be non-differential in relation to exposure resulting in a loss of precision but no bias of the PR..[38] Further, a one-time measurement may not provide information regarding potential variability over time. Similarly, measuring personal exposure once for 24 hours may not reflect typical long-term exposure as measurements are highly dependent on particular activities on the measurement day. Kitchen measurements in particular may overestimate exposure since it is unlikely that the participant spends all her time in the kitchen when the stove is in use. Error in exposure assessment would also likely be non-differential; likely the bias would be towards the null for dichotomized exposure but could go in either direction if there are more than two categories of exposure.[39]. Although we adjusted for important confounders, residual confounding is still a possibility.

$PM_{2.5}$ and BC may be surrogates for other health-damaging pollutants that we did not directly measure. Furthermore, due to the high correlation between $PM_{2.5}$ and black carbon we did not run any models with both pollutants. Generalizability of our stove type results may be limited as other countries use different cleaner-burning stoves and/or fuels. Finally, factors that influence susceptibility to air pollution exposure include age, sex, genetics, underlying health, obesity, diet, smoking status, socioeconomic status, and psychosocial stressors.[40-42] Our results may, therefore, not apply to other populations with different underlying characteristics.

This study also had several strengths. All exposure and health metrics were directly measured without relying on proxies or self-report. Additionally, the use of HbA1c rather than blood glucose is a strength as HbA1c is a measure of blood sugar of the past three months and is, therefore, not influenced by short-term dietary intake.[43] Furthermore, this is one of the first studies to evaluate these important health endpoints in relation to household air pollution.

Conclusions

We observed evidence supporting an association between household air pollution and prevalent diabetic status and limited evidence that these associations were stronger among older women. These results are consistent with growing evidence from ambient air pollution and, in context with the broader literature and, if supported by further research results, may have important implications regarding the impact of household air pollution on the global burden of disease.

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Disclosures

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. Two of the authors, Sebastian Africano of Trees, Water & People (TWP), and Anibal Benjamin Osorto of Asociación Hondureña para el Desarrollo (AHDESA), are members of the implementing non-governmental organizations that deploy the cookstove technology studied in this paper. Results of research like this are often shown as evidence of the effectiveness of this particular cookstove technology in TWP and AHDESA publications, including blogs, articles, and grant proposals, which may lead to future funding of these initiatives by individual and/or institutional supporters of the respective organizations. As such, we disclose this information for your review.

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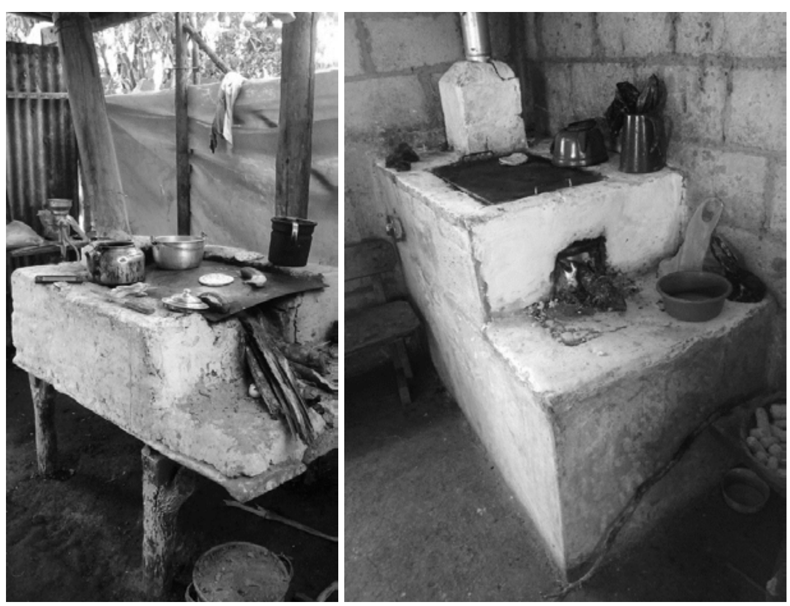

Figure 1

Examples of typical traditional cookstoves (left and middle) and a *Justa* (right) cookstove, in study communities near La Esperanza, Western Honduras

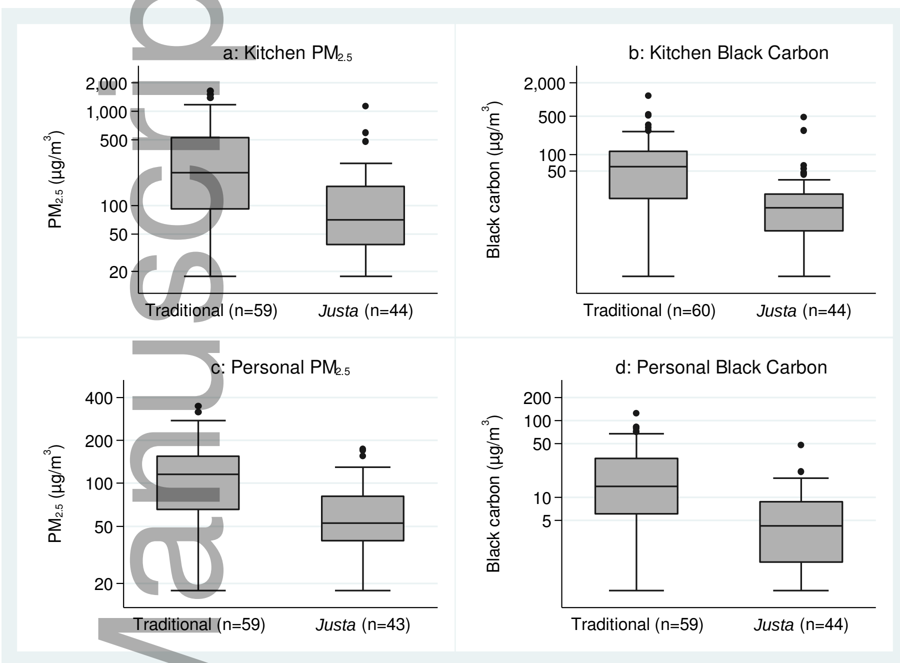

Figure 2a-2d: Distributions of 24-hour mean kitchen and personal $PM_{2.5}$ and black carbon concentrations for traditional and *Justa* stoves, Honduras.

The lower boundary of the box (closest to zero) indicates the 25th percentile, the line within the box marks the median, and the upper boundary of the box (farthest from zero) indicates the 75th percentile. Bars indicate the 10th and 90th percentiles. Y-axes are on the log scale.

$PM_{2.5}$: fine particulate matter

Table 1: Characteristics of study participants and households, for all women and by stove type (traditional and *Justa*), Honduras

	All		Traditional stove owners		*Justa* stove owners
	Mean (SD); range or N (%)	**N**	**Mean (SD); range or N (%)**	**N**	**Mean (SD); range or N (%)**
Age (years)	37.5 (9.0); 25-56	72	38.7 (9.7); 25-56	70	36.3 (8.1); 25-56
Beds per person in household	0.5 (0.2); 0.2-1	72	0.5 (0.2); 0.2-1	69	0.5 (0.2); 0.3-1
>=6 years of school	74 (52.9%)	71	33 (46.5%)	69	41 (59.4%)
Electricity in the house	26 (18.4%)	72	12 (16.7%)	69	14 (20.3%)
Material assets[1]	1.9 (1.3); 0-9	72	1.9 (1.3); 0-5	69	1.9 (1.4); 0-9
Dietary diversity score[2]	6.0 (1.6); 3-10	72	6.1 (1.6); 3-10	70	6.0 (1.5); 3-9
Physical activity[3]	211.7 (106.5); 31-542.5	72	214.2 (114.3); 31-542.5	70	209.2 (98.6); 46.3-444.5
Waist-to-hip ratio	0.88 (0.06); 0.77-1.09	72	0.89 (0.06); 0.79-1.09	70	0.86 (0.05); 0.77-0.99
Waist circumference (cm)	83.5 (8.9); 66.7-111.8	72	84.2 (9.7); 66.7-111.8	70	82.9 (8.1); 67.3-104.1
BMI (kg/m^2)	25.9 (4.2); 17.1-37.5	72	25.7 (4.6); 17.1-37.5	70	26.1 (3.9); 18.2-33.6
24-hour average kitchen temperature (°Celsius)	21.5 (2.9); 12.5-27.2	69	21.9 (3.0); 12.9-27.2	69	21.1 (2.7); 12.5-26.9
Household elevation (meters)	1912 (103); 1729-2171	72	1894 (95); 1737-2152	69	1931 (107); 1729-2171
Had caffeine on measurement day	116 (92.1%)	64	57 (89.1%)	62	59 (95.2%)
Years of cooking	26.0 (9.9); 9-50	72	27.2 (10.6); 9-49	70	24.9 (8.9); 9-50
Length of stove ownership (months)				69	23.6 (17.5); 4-120
HbA1c (%)	5.50 (0.40); 4.1-6.5	72	5.51 (0.36); 4.7-6.5	69	5.48 (0.44); 4.1-6.4
Prediabetes/Diabetes[4]	46 (32.4%)	72	24 (33.3%)	70	22 (31.4%)

BMI: body mass index; HbA1c: glycated hemoglobin; HDL: high density lipoprotein; SD: standard deviation

[1]Material assets were defined by the number of the following items the household possessed: cars, bikes, motorbikes, televisions, radios, refrigerators, sewing machines, electricity.

[2]Scale with values from 1-10 indicating number of food groups included in diet

[3]Estimated weekly metabolic equivalents including the following self-reported activities: cut wood, grind corn (categorized as general kitchen activity with moderate effort), wash clothes, milk the cow, work in the field, carry a heavy weight and walk normally outside the house. For each activity the number of hours per week was calculated and multiplied with the corresponding metabolic equivalent (MET) from the Compendium of Physical Activities.21

[4]Prediabetes was defined as having HbA1c ≥5.7% and ≤6.4%, and diabetes was defined as having an HbA1c level of 6.5% or higher.19

Table 2: 24-hour mean air pollution data for the total population and by stove type among Honduran women using traditional and *Justa* stoves

	All		Traditional stove owners		*Justa* stove owners	
	N	**Mean (SD); range**	**N**	**Mean (SD); range**	**N**	**Mean (SD); range**
24-hour average kitchen $PM_{2.5}$ ($\mu g/m^3$)	103	269 (332); 18-1654	59	367 (378); 18-1654	44	137 (194); 18-1134
24-hour average personal $PM_{2.5}$ ($\mu g/m^3$)	102	100 (67); 18-346	59	125 (74); 18-346	43	66 (38); 18-174
24-hour average kitchen black carbon ($\mu g/m^3$)	104	76 (150); 1-1172	60	108 (179); 1-1172	44	31 (80); 1-469
24-hour average personal black carbon ($\mu g/m^3$)	103	16 (22); 1-123	59	24 (26); 1-123	44	7 (8); 1-47

SD: standard deviation; $PM_{2.5}$: fine particulate matter

Table 3: Adjusted prevalence ratios for the association of prevalent prediabetes/diabetes from HbA1c per IQR increase in 24-hour average pollution or in relation to reference value, Honduras, traditional and *Justa* stove users

	N	IQR	PR per IQR increase or vs	95% CI

			reference	
Kitchen $PM_{2.5}$ ($\mu g/m^3$)	101	312	1.23	1.05-1.44
Personal $PM_{2.5}$ ($\mu g/m^3$)	101	84	1.49	1.11-2.01
Kitchen BC ($\mu g/m^3$)	102	74	1.11	1.06-1.16
Personal BC ($\mu g/m^3$)	101	14	1.26	1.13-1.40
Stove type				
Justa	69		ref	
Traditional	71		1.00	0.63-1.58

Adjusted for age (continuous), dietary diversity score (continuous), years of school (<6 years, >=6 years)

BC: black carbon; CI: confidence interval; HbA1c: glycated hemoglobin; IQR: interquartile range; $PM_{2.5}$: fine particulate matter; PR: prevalence ratio

Table 4: Adjusted mean difference in HbA1c per 1 unit increase in log-transformed 24-hourpollution measurements or in relation to reference value, Honduras, traditional and *Justa* stove users

	N	Adjusted mean difference in HbA1c	95% CI
Kitchen $PM_{2.5}$ ($\mu g/m^3$)[1]	103	0.028	-0.029-0.086
Personal $PM_{2.5}$ ($\mu g/m^3$)[1]	102	0.042	-0.061-0.144
Kitchen BC ($\mu g/m^3$)[1]	104	0.028	-0.014-0.069
Personal BC ($\mu g/m^3$)[1]	103	0.029	-0.021-0.079
Stove type[2]			
Justa	68	ref	
Traditional	72	-0.012	-0.143-0.119

Adjusted for age (continuous), dietary diversity score (continuous), number of beds (continuous), BMI (continuous), physical activity (continuous)

[1]Adjusted mean difference in HbA1c per log increase in pollution

[2]Adjusted mean difference in HbA1c vs reference

BC: black carbon; CI: confidence interval; HbA1c: glycated hemoglobin; $PM_{2.5}$: fine particulate matter; BMI: body mass index

P-values for adjusted mean differences: kitchen $PM_{2.5}$: 0.33; personal $PM_{2.5}$: 0.42; kitchen BC: 0.19; personal BC: 0.25; stove type traditional: 0.86