

Biomass fuel exposure and asthma symptoms among rural school children in Nigeria

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ABSTRACT

Background: Approximately 70% of rural Nigerian households rely on biomass fuels for cooking. The International Study of Asthma and Allergies in Childhood (ISAAC) estimates the prevalence of current wheeze among children in Nigeria to have risen from 10.7% in 1999 to approximately 20% in 2014.

Objective: To examine the effects of biomass smoke exposure on asthma symptom prevalence in rural children.

Methods: We conducted a cross-sectional survey in rural communities in Nigeria. Asthma symptoms were defined according to ISAAC definitions. Biomass smoke exposure was determined by the types of fuel used for cooking. Logistic regression was used to explore associations between biomass smoke and asthma symptoms.

Results: The study population comprised 1,690 schoolchildren, of which 865 lived in households cooking with biomass and 825 lived in households not using biomass. Asthma symptoms were reported in 481 (28.5%) children. Biomass fuel was associated with increased odds of asthma symptoms. Adjusted odds ratios (aORs) were 1.38 (95% CI: 1.05–1.80) for nocturnal cough, 1.26 (95% CI: 1.00–1.61) for current wheeze, and 1.33 (95% CI: 1.05–1.69) for report of any asthma-related symptoms. Sex modified the associations between asthma symptoms with biomass fuel: aORs were stronger and significant for males (nocturnal cough = 1.85, 95% CI: 1.24–2.76; current wheeze = 1.48, 95% CI: 1.03–2.13; report of any asthma-related symptoms = 1.60, 95% CI: 1.12–2.28), but weaker and non-significant for females.

Conclusion: The risk of asthma symptoms related to biomass smoke exposure appears to differ by sex.

Keywords: Biomass fuel, asthma symptoms, school children, rural, Nigeria.

INTRODUCTION

Asthma is a heterogeneous syndrome characterized by wheezing, chest tightness, shortness of breath, and/or cough or a combination of two or more of these symptoms. It is the most common chronic disease in children and accounts for substantial morbidity as measured by hospitalizations, school absences, and healthcare costs [1–2]. About 334 million people worldwide suffer from asthma [1]. The International Study of Asthma and Allergies in Childhood (ISAAC) estimated that the annual economic impact of asthma could range from US\$49 million to US\$8.3 billion in high-income countries (HICs) [1]. Despite advancement in the management of asthma, the last few decades have seen a dramatic increase in the prevalence of asthma and respiratory symptoms among children, especially in low- and middle-income countries (LMICs). Specifically, the prevalence of asthma among children under age 15 years in Africa increased by 45.7% between 1999 (34.1 million cases) and 2010 (49.7 million cases) [3]. This increased prevalence may be linked to increasing population growth and/or increased awareness of asthma in wheezing children [4], but a robust explanation is lacking. Factors that have been strongly implicated include higher exposure to certain environmental agents and changes in lifestyles, which includes urbanization [1,5]

Among a range of environmental factors, exposure to heavy traffic pollution [6–7], tobacco smoke [8–9], dust mites [10], indoor dampness and molds [11] and pets [6] have been found to be adversely associated with asthma. Currently, evidence linking biomass smoke exposures to adverse respiratory conditions (including asthma) are beginning to emerge. A recent

meta-analysis revealed a positive association between smoke exposure from biomass fuel and chronic bronchitis, airflow limitation, and chronic obstructive pulmonary disease (COPD) [12]. In a study conducted in three rural communities in Nigeria, respiratory symptoms such as chest tightness, dry cough, and difficulty breathing were observed among children in households using biomass as source of domestic cooking energy [13]. Similarly, among rural children from Venezuela, biomass smoke from wood used for cooking was associated with a higher risk of asthma symptoms [14]. Exposure to biomass smoke has also been linked to acute respiratory infections (ARI) [15–17] and chronic bronchitis [16]. However, the link between biomass fuel exposure and asthma morbidity is not yet conclusive, and more studies are necessary to evaluate if biomass fuel is associated with asthma and the strength of the association.

Approximately 50% of the world's population, and up to 90% of rural populations in developing countries, relies on biomass fuels (wood, charcoal, dried animal dung, and agricultural residues) as its primary source of domestic cooking energy [18]. The World Health Organization (WHO) estimated that approximately 1.9 million deaths from respiratory diseases are attributed to biomass smoke exposure, which places biomass smoke as the leading environmental risk factor worldwide [19].

In Nigeria, over 70% of rural households rely primarily on wood stoves for cooking [20]. This cooking method is believed to be the major contributing factor to the estimated 3.8% of the total national burden of disease in Nigeria, including respiratory diseases [21]. Recently, the ISAAC team estimated that the prevalence of current wheeze among children in Nigeria has risen from 10.7% in 1999 to approximately 20% in 2014 [1]. Despite the alarmingly increasing rate, there are few studies assessing the relationship between biomass smoke exposure and

childhood asthma or asthma-related symptoms in rural households in Nigeria. Some of these studies are either inconclusive in their reports on asthma and asthma symptoms [22–23], have only focused on objective assessment of lung function as indications of respiratory morbidity [13,24–25], or have only been conducted among adult populations [24,26].

Previously, we reported high frequencies of respiratory symptoms in children in rural households using biomass fuels as sources of domestic cooking energy [13]. The current study sought to expand on that work by examining the relationships between biomass smoke exposure and asthma symptoms in rural schoolchildren.

MATERIALS AND METHODS

Study design and population

This study was a cross-sectional study conducted among 1,690 children (aged 6–21 years) attending primary and secondary schools in three contiguous rural communities in Ibadan, Nigeria: Aba-Nla, Eruwa and Igbo-Ora. Households in these communities were predominantly homogeneous in terms of socioeconomic status, home construction, and access to health care. Children from these communities were initially recruited for participation in our previous rural health studies [27–28] and have since formed a suitable sampling cohort for subsequent studies with our team. The major source of occupation for households in these communities was farming. The majority of these households are largely dependent on wood fuel as source of domestic cooking energy with an occasional supplement of crop residues. Households in these communities spend, on average, five hours per day cooking with biomass fuels [13]. As a result, women and children receive substantial daily biomass smoke exposure. All schools in the three

rural communities (7 elementary schools and 9 high schools) were approached for participation in the study. A total of 2,315 questionnaires were distributed to students, and 1,690 questionnaires were completed and returned to the schools for pick-up by study personnel.

Study instrument

The standardized, validated ISAAC questionnaire, with some modifications based on the objective of the study, was administered [29]. In addition to completing questions about asthma and respiratory symptoms in the ISAAC questionnaire, parents or guardians also completed questions on household fuel types used for cooking. For easy understanding, the ISAAC questionnaire was translated from English to Yoruba (the commonly spoken language in the community) and was then reverse-translated for accuracy at the Department of Linguistics at the University of Ibadan. Of note, the ISAAC questionnaire has been validated in a number of languages and used in many countries to allow for international comparison [30]. The translated version of this questionnaire was pilot-tested in our initial study in similar rural communities [13] and adjusted after discussions with other health workers and the representatives of each community.

Operational definition of outcome variables

The information on respiratory health outcomes of diagnosed asthma, nocturnal cough, and wheeze was ascertained from the ISAAC questionnaire. “Diagnosed asthma” was operationally

defined as a history of physician-diagnosed asthma *and* any episodes of asthma in the past 12 months, as reported on the questionnaire. “Ever wheeze” was defined based on an affirmative response to the following: “Has your child ever had wheeze or whistling in the chest?” “Current wheeze” was assigned to the child if the wheeze or whistling in the chest had occurred in the past 12 months. Likewise, nocturnal cough was ascertained with the following question: “In the past 12 months, has your child had dry cough at night apart from a cough associated with a cold or chest infection?”

Predictor variables and other covariates

In addition to the ISAAC respiratory questions, information was obtained on biomass smoke exposure for each child based on household cooking fuel types. One parent or guardian per household responded to the question: “What fuel type is mainly used for cooking in your house?” The options to choose from were “cow dung/animal residue,” “firewood,” “charcoal,” “liquefied petroleum gas (LPG),” “electricity,” and “other.” If respondents chose “other,” they also specified which fuel they used. Since households can use a combination of fuel types, respondents could choose more than one category. Responses to the question above were used to group children into two distinct categories. Children from parents using cow dung/crop residue, firewood, charcoal, or a combination of two or more of these household fuel types were classified as “Children from households using biomass fuels.” The remaining children from clean energy households using LPG and/or electricity were classified as being from “No biomass fuel using households.” This two-category classification of domestic energy sources forms the

principal predictor variable in this study (biomass smoke exposure vs. no biomass smoke exposure), with the “no biomass smoke” individuals as the reference group.

Covariates

We also obtained information on covariates of importance such as age, sex, maternal levels of education, tobacco exposure, and indoor environmental characteristics. Parents or guardians completed three questions on tobacco smoke exposure: 1.) “Does your child smoke?” 2.) “Do you currently smoke cigarettes?” and 3.) “Does anyone in your house currently smoke cigarettes?” Information from these questions was used to ascertain parental smoke and environmental tobacco smoke exposure by the child. Finally, indoor exposure to pets was assessed by the response to a question about pets in the home: “In the past 12 months have you had cat and/or dog in your home?”

Statistical analysis

The full data from the 1,690 participants that completed the survey were included in the statistical analysis for this study. Categorical demographics, environmental exposures, and respiratory symptoms were compared between children from the two household types using the χ^2 test, while continuous variables were compared using independent *t*-tests. Univariate and multivariate logistic regression analyses were performed to assess the relationships between household cooking fuel types and asthma symptoms. Only variables with $p \leq 0.25$ in the univariate analysis were entered into a multivariate logistic regression models. Separate multivariate models were fitted for each outcome of diagnosed asthma and asthma symptoms. The strength of the associations were assessed using odds ratios (ORs) with 95% confidence

intervals (CIs), and statistical inference was based on $p < 0.05$. Because the involvement of children in domestic cooking and food preparation is likely to differ by sex in many rural communities, we also assessed the presence of interaction between sex and household biomass fuel types; results were presented by stratified analysis. All analyses were completed with the Statistical Package for the Social Science (SPSS) Version 23 (SPSS Inc. Armonk, NY: IBM Corp.) and the Statistical Analysis System (SAS) Version 9.4 (SAS Institute Inc., Cary, NC, USA).

Ethical approval

Return of the completed questionnaire with a corresponding signed parental consent and child assent form by the parent or guardian of each child signified voluntary consent to participate in the study. Approval to conduct the study was obtained from the Institutional Review Board on Human Research at the University of Ibadan, Nigeria (Approval Number: UI/EC/09/0133) and the University of Chicago, USA (Approval Number: 09-336-B). Because of the community-based nature of the study, approval to conduct the study was also obtained from the Oyo State Ministry of Education, Ibadan, Nigeria and all principals of the schools attended by the children.

RESULTS

In total, 1,690 school children participated in this study. The response rate was 73% based on the 2,315 questionnaires that were originally sent out to parents or guardians for completion. In our study population, 51.1% of the children lived in households where biomass fuels were used for cooking and were exposed to biomass smoke, while 48.9% lived in households where cleaner fuels were used. Table 1 shows the distribution of personal and environmental characteristics, as

well as the prevalence of respiratory health outcomes among children based on household's biomass fuel status. A lower proportion of children from the biomass fuel households were male compared to the non-biomass fuel households, and children from non-biomass fuel households were older than children from the biomass fuel households. Also, there were significant differences in mothers' education levels and in pet ownership (presence of both cat and dog in the home) between the study groups, while a borderline significance was observed for tobacco smoke exposure.

The overall prevalence of diagnosed asthma and asthma symptoms in the study population was 2.2% and 28.5%, respectively. Although the prevalence of diagnosed asthma differed between the two groups, with a higher prevalence in children from biomass fuel households (2.3%), the difference was not statistically significant. When the two groups were compared for asthma symptoms, the prevalence of "ever wheeze" (wheezing at any point in time) did not differ by household cooking fuel types. All other asthma symptoms considered differed significantly between the two groups (nocturnal cough: 23.3% vs. 17.3%; current wheeze: 28.2% vs. 23.3% for biomass fuel and non-biomass fuel households, respectively). Children from biomass fuel households were significantly more likely to experience at least one or more of the three respiratory symptoms evaluated (31.3% vs. 25.5%).

Table 2 presents the unadjusted associations between personal and environmental risk factors for diagnosed asthma and asthma symptoms. Higher maternal education level significantly decreased the risk of nocturnal cough, current wheeze, and any respiratory symptoms among the children. Of the environmental risk factors assessed, only the presence of a dog in the home was associated with an increased risk of asthma; it was also positively

associated with nocturnal cough, current wheeze, and any respiratory symptoms. While biomass smoke exposure was positively associated with diagnosed asthma and all asthma-related symptoms, it was only statistically significant for nocturnal cough, current wheeze, and any of the respiratory symptoms evaluated. A similar association was observed if a cat was present in the home. However, the presence of a cat and a dog in the home was positively associated with all of the respiratory symptoms suggestive of asthma. Finally, increasing age was associated with a reduced risk of ever wheezing, current wheeze, and any respiratory symptoms evaluated.

Table 3 presents the findings from the adjusted analyses for report of diagnosed asthma and the various respiratory symptoms. After adjusting for all variables associated with asthma or asthma-related symptoms from the univariate analyses, biomass smoke exposure continued to be significantly positively associated with nocturnal cough, current wheeze, and any (or a combination of the three) asthma-related symptoms. This association was not significant for diagnosed asthma or ever wheezing.

Finally, we assessed the presence of interaction between sex and household fuel types. When we considered current wheeze, nocturnal cough, and the presence of any of the respiratory symptoms evaluated as outcomes, the prevalence of current wheeze and any of the asthma symptoms were significantly higher in females than males (current wheeze: 27.9% vs. 23.8%, $p = 0.05$; any: 31.1% vs. 26.0%, $p = 0.021$: [Data not shown]); there was a statistically significant interaction between household fuel types and sex ($p < 0.05$ for all three outcomes). After stratification by sex, the positive associations between biomass smoke and current wheeze, nocturnal cough, and any symptoms of asthma (ever wheezing, current wheeze, and/or

nocturnal cough) were stronger and remained statistically significant for males; the associations were weaker and not statistically significant for females (Table 4).

DISCUSSION

The aim of this study was to assess the relationships between biomass smoke exposure and asthma symptoms among rural schoolchildren. Compared to children from non-biomass fuel households, children exposed to biomass smoke reported significantly higher prevalence of asthma symptoms (nocturnal cough and current wheeze). Overall, findings from this study show that biomass smoke exposure is adversely associated with asthma symptoms in rural schoolchildren. However, these associations were not consistent between sexes. After adjusting for confounders, children exposed to biomass smoke continued to demonstrate higher risk for asthma symptoms, but this effect was confined to male children and not for females.

In addition to biomass fuel, pet ownership (cat, dog, or both in the home) was associated with asthma and/or asthma symptoms in univariate analyses. While several studies have investigated the role of pet exposures in relation to asthma and asthma-related symptoms, the findings have been inconsistent and sometimes conflicting; some studies show protective effects [31–32] and others show risk effects [33–34]. These discrepancies between studies are not necessarily surprising considering possible variations in study design and population characteristics, as well as in duration and intensity of exposure. In our study population, similar to many rural African communities, pets (cats or dogs) are not necessarily kept inside the home, but rather as agents for rodent control around the home. Therefore, both the duration and dosage

of exposure are likely to differ for these children, which may present a different pattern of disease risk compared to children from many affluent countries.

Studies examining the effects of indoor biomass smoke exposure on the development of respiratory conditions, including asthma and asthma symptoms, are not uniformly positive. While several previous studies did not observe a significant association between asthma symptoms and indoor smoke exposure from burning biomass fuels [23,35–37], our study showed evidence to support a connection between biomass smoke exposure and asthma symptoms. This is similar to what has been observed in studies from Guatemala [38], Nepal [39], and Venezuela, [14] where children from rural households using biomass wood fuel for cooking had significantly higher risk of asthma symptoms compared to children from households using cleaner fuels.

While the above studies demonstrated adverse links between asthma symptoms and biomass fuel exposure, our finding that the effect of biomass fuel exposure was greater for males and nonexistent for females offers noteworthy information about sex-specific interactions with biomass smoke exposure in this population of schoolchildren. Customarily, cooking in developing countries is often done by adult females who are more exposed to cooking smoke than males [18,40]. As such, the magnitude of association between biomass smoke exposures is expected to be higher for females than males. Our study demonstrated that this trend may not hold when children are considered. The reason for this is unclear in this study, but we posit that it may be specific to the exposure trends for male children in these communities. Children often assist their mothers in kitchen while they cook; infants and toddlers are often carried on their mothers back, which is a common cultural practice in many rural settings in Nigeria [41]. It has

been reported that female children were more likely to be carried on their mother's back during cooking than males [42]. However, it may be suggested that mothers in the rural communities we studied were more likely to carry male children than females or to keep them in the kitchen area while cooking, thus predisposing them to greater risk of asthma symptoms due to smoke from biomass fuel. Also, it may be due to differential underreporting of respiratory symptoms for female children by their mothers. A biological explanation may be the obvious natural history for childhood asthma and asthma-related symptoms; studies have shown that males, compared to females, are consistently more at-risk of asthma and asthma symptoms, particularly wheeze, during early childhood, with the pattern reversing during adolescence when symptoms are more common in females [43–46]. Specifically, the incidence and prevalence of asthma symptoms are higher in females at age 15 years and beyond [47–48]. In the aforementioned studies, male sex appears to be an important element in the development of asthma and asthma-related symptoms during childhood. The average age of children in our study was 13.5 years, and children from non-biomass households were about 0.6 years older, on average, than children from biomass fuel households. Because we adjusted for age in our models, we do not feel that the stronger associations observed for males in the biomass household group was explained by the age differences between the two groups; rather, the associations may have coincided with the peak period of asthma symptoms prevalence in male children. Thus, the findings from our study are consistent with the general perspective that male children are often more susceptible to asthma and asthma related symptoms during early childhood than female children.

Sex-linked differences in the prevalence and incidence of asthma and asthma-related symptoms are well-known, with consistently higher prevalence and incidence in females [49]. In

a study among 156,316 participants in India, effects of cooking smoke from biomass fuel on asthma was greater for women, but nonexistent for men [50]. Similar results were also found in a cross-sectional study by Mishra in India where the use of biomass fuel was associated with asthma only in women [51]. Findings from these studies suggest that the risk of biomass smoke exposure for asthma may be confined to women due to their duration of exposure and compromised respiratory system from cooking smoke [51]. We demonstrated that this pattern may not be observed in Nigerian rural children after all, especially with regards to asthma symptoms. This is consistent with results from a study conducted in India which investigated the effects of cooking smoke from biomass fuel on ARI, defined as chronic cough in the past 2 weeks accompanied by rapid breathing, among children age 3 years and below [52]. The study identified that not only was the prevalence of ARI higher for boys than girls, but also the effect of biomass smoke on ARI was considerably stronger and significant for boys than for girls. Part of the explanations described for this gender difference was a discrimination against female children in India, making more male children to be present in kitchen with their mothers during cooking. However, our observation of male-linked effects of biomass smoke and asthma symptom in this present study further proved that the initial results observed in India may have nothing to do with gender discrimination, but rather may be a true effect that represents the exposure pattern for male children in such rural settings.

The study population for the India study was comprised of infants and toddlers (≤ 3 years). Thus, it may be argued that the results may not offer direct comparison to our results. However, the recent ISAAC Phase III study provides a suitable comparison. In a study among 154,309 adolescents from 31 countries, Wong et al. [53] observed consistent adverse

associations between biomass smoke from use of open fire and the risk of asthma symptoms (current wheeze) for both sexes after adjusting for confounding variables: male (6-7 years: OR = 2.35; 95% CI: 1.64–3.37; 13–14 years: OR = 1.36; 95% CI: 1.03–1.78) and females (6–7 years: OR = 1.93; 95% CI: 1.23–3.02; 13–14 years: OR = 1.36; 95% CI: 1.04–1.78) [53]. In contrast to the ISAAC study, we did not observe a significant association for females, but our study mirrors similar associations observed for male children in this study, suggesting that biomass smoke exposure remains a significant and important risk factor for childhood asthma morbidity and that the effects may be sex-linked.

The mechanism by which exposure to biomass fuel affects respiratory health is still not well understood. Oxidative stress remains the most commonly cited explanation. Smoke emanating from burning biomass fuels contains toxic pollutants, generally referred to as oxidants, including volatile organic compounds (VOCs), particulate matter (PM), carbon monoxide (CO), and oxides of nitrogen, sulfur and fluorine [19]. The relationship between biomass smoke and respiratory responses appears to be linked to oxidative stress brought about by imbalances between biological pro-oxidants and anti-oxidant defense systems is believe to initiate cytokine production and depression of protective membrane [19,54]. The high levels of oxidative stress that are related to wood smoke exposure further mediates inflammatory responses or worsen asthma condition due to a compromised anti-oxidant defense system [19]. This perceived mechanism may be one of the reasons previous studies have observed greater risks of respiratory conditions that are linked to biomass smoke exposure in females compared to males because of sex differences in nutritional status and women's compromised respiratory system due to longer duration of exposure to biomass smoke [51]. Since only a few gender-

stratified analyses of effects of biomass smoke on asthma or asthma symptoms are available, it is unclear if greater smoke exposure in women necessarily leads to greater risk for these respiratory conditions. In our previous study in rural communities similar to current population in this study, we observed significantly reduced levels of antioxidants in children [25]. However, whether the observed results were sex-specific for this population remains to be determined.

There are a number of limitations to our study. The cross-sectional nature of the study precluded establishing temporal relationships. Because our outcomes were based on prevalence of asthma and asthma-related symptoms rather than incidence, it remains unknown in this study whether smoke exposure from biomass fuel is causally associated with asthma symptoms. Moreover, there is no information available on the incidence of asthma symptoms due to biomass smoke exposure, as there are no prior studies that have assessed this relationship in a prospective cohort[55]. Therefore, while we observed sex-specific link between biomass smoke exposure and asthma symptoms, the results should be interpreted with caution.

The estimate of asthma symptoms in this study may be somewhat biased toward the biomass using households because these households might have shifted cooking fuel types from biomass to cleaner fuels, either due to their children's respiratory symptoms or improved socioeconomic status. It is also possible that children in the non-biomass using households had at one point in time lived in biomass households and thus were exposed to biomass smoke. Therefore, the true effect of biomass smoke exposure on asthma-related symptoms might be larger than what we estimated. Although we do not feel this was the case in this population, the lack of information regarding the duration of biomass fuel exposure prevented us from assessing dose-response effects in this study.

Furthermore, we used parental report of asthma and asthma symptoms instead of objective measures. There could be variations and inconsistencies in the ways the parents perceived or understood the symptoms or questionnaires, which could have led to misclassifications of outcomes. However, we feel this bias was minimized to a great deal in this study, if not completely eliminated, by translating the questionnaire to the local language that is commonly spoken and understood by the rural participants. While we recognize that self-report of asthma is not as accurate as clinical measures, validated instruments, such as the ISAAC questionnaire used in this study, have been shown to be as accurate as clinical measures [56]. Also, questionnaire reports of asthma symptoms in children have been previously validated against objective clinical assessment of asthma and has shown high sensitivity (current wheeze: 0.78; nocturnal cough: 0.80) and specificity (current wheeze: 0.97; nocturnal cough: 0.90) [57]; this indicates that questionnaire reports of asthma and asthma symptoms are valid, and it still forms the basis for defining asthma in epidemiological settings.

Family history of asthma is a significant risk factor for asthma and asthma-related symptoms in children [58–59]. Information regarding family history of asthma and asthma-related symptoms was lacking in this study. Assessing family history of asthma among these rural children would have improved our results by eliminating some of the residual confounding that may have been attributed to this factor. We hope to untangle this in future efforts and to also assess its interactions with biomass fuel exposure that may bear sex-specific disease and/or symptoms prevalence.

Despite the above limitations, we feel that the results of this study provide further estimates of the prevalence rates of asthma symptoms among schoolchildren in rural settings in

Nigeria, where such studies are relatively lacking. It also provides insight into the possible roles of biomass smoke exposure as a risk factor for asthma symptoms. Our findings support previous works that demonstrate negative impacts of biomass smoke exposure on asthma and asthma-related symptoms. While the causes of increased risk of asthma-related symptoms among children in our study population may still remain unknown, our observation of increased symptoms risk due to biomass smoke exposure, and that is confined solely to male children, is intriguing. Whether this represents a response to an exposure pattern that is unique to this population alone, or an exposure pattern that is common to many rural populations in Nigeria that are reliant on biomass fuel for domestic cooking energy remains to be determined. However, our results extend the spectrum of environmental risk factors that may be contributing towards increasing asthma morbidity in Nigeria as reported in the current ISAAC study [1].

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CONFLICT OF INTEREST

The authors have no conflict of interest related to this study. The authors alone are responsible for the content and writing of this manuscript.

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Table 1: Personal and environmental characteristics and respiratory health outcomes of children by household biomass fuel status

	Children from biomass fuel households (n = 865)	Children from no biomass fuel households (n = 825)	P value
Demographics			
Mean age, years ($\pm$ SD)	13.3 (2.7)	13.9 (2.6)	<0.001
Sex, %			
Male	50.1	53.3	0.178
Mother's level of education, % >= High school (%)	11.0	18.4	<0.001
Environmental exposure, %			
Parental smoke	0.9	0.6	0.453
Environmental tobacco smoke	12.6	9.7	0.058
Pet ownership, cat	14.8	12.6	0.191
Pet ownership, dog	25.2	21.2	0.052
Pet ownership, cat and dog	32.9	28.1	0.031
Respiratory outcomes, %			
Asthma*	2.3	1.7	0.724
Nocturnal cough	23.2	17.3	0.003
Ever wheeze	13.2	12.0	0.465
Current wheeze	28.2	23.3	0.020
Any of asthma symptoms†	31.3	25.5	0.007

*Report of physician-diagnosed asthma.

†Presence of one or a combination of two or more of the three respiratory symptoms (dry cough, ever wheeze, and current wheeze).

Table 2: Unadjusted (univariate) associations between personal and environmental characteristics and respiratory health outcomes among the study population

	Asthma	Nocturnal cough	Ever wheeze	Current wheeze	Any symptom[‡]
Variables	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Household fuel type					
No biomass fuel	1.00	1.00	1.00	1.00	1.00
Biomass fuel	1.13 (0.59–2.16)	1.44 (1.14–1.84)^a	1.11 (0.84–1.49)	1.30 (1.04–1.61)^a	1.34 (1.08–1.65)^a
Sex					
Male	1.00	1.00	1.00	1.00	1.00
Female	0.88 (0.46–1.70)	0.86 (0.68–1.08)	0.81 (0.60–1.08)	0.81 (0.65–1.00)	0.78 (0.63–0.96)^b
Mother education					
< High school	1.00	1.00	1.00	1.00	1.00
≥ High school	0.97 (0.33–2.83)	0.52 (0.33–0.81)^a	0.88 (0.55–1.40)	0.58 (0.39–0.85)^a	0.61 (0.42–0.88)^a
Environmental tobacco smoke					
No	1.00	1.00	1.00	1.00	1.00
Yes	0.69 (0.21–2.29)	1.10 (0.76–1.58)	1.01 (0.64–1.59)	1.03 (0.74–1.46)	1.04 (0.74–1.44)
Pet ownership					
Cat					
No	1.00	1.00	1.00	1.00	1.00
Yes	1.22 (0.50–2.96)	1.56 (1.14–2.14)^a	1.28 (0.86–1.89)	1.35 (1.00–1.83)^a	1.36 (1.01–1.82)^a
Dog					
No	1.00	1.00	1.00	1.00	1.00
Yes	2.05 (1.04–4.02)^a	1.34 (1.03–1.76)^a	1.75 (1.28–2.39)	1.53 (1.19–1.95)^b	1.65 (1.30–2.09)^b
Both cat and dog					
No	1.00	1.00	1.00	1.00	1.00
Yes	1.39 (0.71–2.73)	1.39 (1.08–1.78)^a	1.53 (1.14–2.07)^a	1.48 (1.17–1.86)^b	1.51 (1.21–1.89)^b
Age (per year)	0.97 (0.86–1.10)	0.96 (0.92–1.01)	0.94 (0.89–0.99)^a	0.95 (0.92–0.99)^a	0.95 (0.92–0.99)^a

^a $P < 0.05$; ^b $P < 0.001$

‡Presence of one or a combination of two or more of the three respiratory symptoms (dry cough, ever wheeze, and current wheeze).

Table 3: Adjusted^a associations between biomass fuel exposure and outcome of report doctor diagnosed asthma and asthma-related symptoms.

Outcome	OR (95% CI)	P-value
Asthma*	1.30 (0.60–2.78)	0.506
Nocturnal cough	1.38 (1.05–1.80)	0.021
Ever wheeze	1.14 (0.82–1.57)	0.438
Current wheeze	1.26 (1.00–1.61)	0.045
Any of asthma-related symptoms	1.33 (1.05–1.69)	0.020

^aEach model adjusted for mother education level, pet ownership, environmental tobacco smoke, sex, and age

*Report of physician-diagnosed asthma.

Table 4: Associations between biomass fuel exposure and outcome of asthma-related symptoms, stratified by sex and household fuel status.

Outcomes	Males		Females	
	Biomass fuel (<i>n</i> = 433)	No biomass fuel (<i>n</i> = 440)	Biomass fuel (<i>n</i> = 432)	No biomass fuel (<i>n</i> = 385)
Asthma; <i>n</i> (%)				
Yes	9 (2.1)	9 (2.0)	11 (2.5)	8 (2.1)
No	424 (97.9)	431 (98.0)	421 (97.5)	377 (97.9)
aOR (95% CI)	0.92 (0.30–2.81)		1.77 (0.59–5.29)	
Nocturnal cough; <i>n</i> (%)				
Yes	106 (24.5)	61 (13.9)	95 (22.0)	82 (21.3)
No	327 (75.5)	379 (86.1)	337 (78.0)	303 (78.7)
aOR (95% CI)	1.85 (1.24–2.76)^a		1.03 (0.71–1.50)	
Ever wheeze; <i>n</i> (%)				
Yes	56 (12.9)	44 (10.0)	58 (13.4)	55 (14.3)
No	377 (87.1)	396 (90.0)	374 (86.6)	330 (85.7)
aOR (95% CI)	1.33 (0.82–2.18)		0.92 (0.59–1.44)	
Current wheeze; <i>n</i> (%)				
Yes	122 (28.2)	86 (19.5)	122 (28.2)	106 (27.5)
No	311 (71.8)	354 (80.5)	310 (71.8)	279 (72.5)
OR (95% CI)	1.48 (1.03–2.13)^a		1.04 (0.73–1.46)	
Any of asthma- related symptoms; <i>n</i> (%)				
Yes	135 (31.2)	92 (20.9)	136 (31.5)	118 (30.6)
No	298 (68.8)	348 (79.1)	296 (68.5)	267 (69.4)
aOR (95% CI)	1.60 (1.12–2.28)^a		1.06 (0.76–1.49)	

Each model adjusted for mother education level, pet ownership, environmental tobacco smoke, and age.

*Report of physician-diagnosed asthma.

^a*P* < 0.05