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A cross-sectional analysis of respiratory ill-health among charcoal workers and its implications for strengthening occupational health services in southern Nigeria

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ABSTRACT

Objectives This study was conducted to assess the concentration of air pollutants at charcoal sites, the dose-response relationship between site-based exposure levels to air pollutants and prevalence of respiratory symptoms among charcoal workers, and the measures these workers employ to safeguard their health.

Design Cross-sectional but comparative design

Setting Charcoal production kiln sites in Sapele, Delta State, Nigeria.

Participants Overall 296 charcoal workers and age-matched, sex-matched and height-matched non-exposed traders (comparison group).

Primary and secondary outcome measures The primary outcome measure was the prevalence of respiratory symptoms among charcoal workers while secondary outcomes included lung function indices as well as hazard control practices among charcoal workers.

Results Majority (83.3%) of the sites had PM_{10} and $PM_{2.5}$ values five times higher than the WHO standard. Charcoal workers were more likely to have respiratory symptoms; wheeze was statistically significant after adjusting for confounders, (OR 4.22; CI 1.37 to 12.99). The dose-response relationship between site-based exposure levels to air pollutants and the prevalence of respiratory symptoms among charcoal workers was statistically significant for all symptoms except chest tightness (p=0.167). Mean forced expiratory volume in the first second (FEV_1) and forced vital capacity (FVC) were considerably lower among workers with differences of −0.22 (−0.42 to −0.05) L and −0.52 (-0.76 to −0.29) L, respectively, whereas FEV_1/FVC ratio and peak expiratory flow rate were higher among workers with mean differences of 5.68 (3.59–8.82)% and 0.31 (-23.70 to 24.43) L/min, respectively; but the mean difference was significant only for the FEV_1/FVC ratio. Charcoal workers had poor hazard control practices; only 3.4% reportedly used personal protective equipment.

Conclusion Air pollutants at kiln sites were higher than WHO standards. Despite the significantly higher prevalence of wheeze, chest tightness and chronic cough among charcoal workers, their hazard control practices were inadequate. Charcoal workers should adopt appropriate hazard control practices, and use improved devices which emit minimal pollutants.

Strengths and limitations of this study

- This study was conducted among workers with low socioeconomic class in an informal setting (no organised industries or plants for charcoal production).
- The comparison group was matched for age and sex with the exposed workers.
- Site-based level of air pollutants dose-response relationship was assessed but personal exposure to air pollutants was not measured.
- Logistic regression was used to control for potential confounders.
- This was a cross-sectional study; a cohort study is preferable for reporting the incidence of occupational lung disease among these workers.

INTRODUCTION

Fossil fuels are a major energy source worldwide; however, biomass including charcoal, is gaining prominence as a viable fuel.[1] In Africa, rural as well as urban dwellers unable to afford expensive energy supplies also depend on charcoal; and due to its optimum energy value and lighter weight charcoal is preferred to other biomass.[2] Accordingly, the demands for charcoal will likely not decline as special delicacies such as barbecue, the roasting of maize, yam or plantain also requires charcoal.[3]

Nonetheless, charcoal production exposes workers directly to wood smoke, which is a blend of gaseous, solid and liquid particles, emanating from charcoal kilns.[4] Wood smoke particularly comprises volatile organic compounds, oxides of carbon, sulphur and nitrogen as well as ammonia,[4] persistent inhalation of which irritates the respiratory tract and induces respiratory diseases and exacerbates pre-existing chronic bronchitis and asthma.[5] Moreover, fine particles in the smoke can persist in the surrounding air and be inhaled by unsuspecting persons not connected with the production process.

The hazard of air pollution is escalating globally and accounts for over 6% of all deaths.[6] Africa is not exempt from this burgeoning menace as it contributes over 170 000 deaths to the annual global burden.[7] In Nigeria, at least 1 in 10 000 persons dies from air pollution-related diseases annually.[8] The picture is precarious in the Niger Delta, southern Nigeria where air pollutants substantially cause respiratory diseases and deaths.[9] Thus, to curtail the adverse health effects of global air pollution, WHO has stipulated 24-hour exposure limits for respirable ($PM_{2.5}$) and (PM_{10}) to be 25 µg/m^3 and 50 µg/m^3, respectively. Above these levels, deaths from cardiopulmonary disease and lung cancer would likely increase with almost absolute certainty following prolonged exposure.[10] Evidence suggests that tobacco smoking and occupations with exposure to wood smoke predispose people to chronic obstructive pulmonary disease (COPD).[11 12] As wood smoke shares similar properties with tobacco smoke its inhalation may be a major public health problem with implications for immediate and long-term respiratory health.[13] Remarkably, studies have reported respiratory symptoms among smoke-exposed workers,[14–16] however with limited information on the dose-response relationship between exposure levels and respiratory symptoms among charcoal workers. Even, as the theme of last year's world environmental health day is directed towards improving air quality,[17] the outcome of this study would provide data that could inspire the development of mechanisms for reducing hazards from charcoal production in Sapele, Delta State. Therefore it became imperative to estimate the concentration of air pollutants at charcoal production sites, with a view to highlighting how far they deviate from WHO air quality standards, their effect on the respiratory health of charcoal workers and the measures these workers employ to safeguard their health.

MATERIALS AND METHODS

Study area, population and design

This cross-sectional study applied a comparative design to explore potential associations between exposure to wood smoke and prevalence of respiratory symptoms among charcoal workers. The comparison group comprised traders, matched for age, sex and height with the exposed workers. Following an initial group counselling and screening, charcoal workers who had not worked up to 1 year, had a history of respiratory disease prior to current job or were unwilling to give consent, were identified and excluded. And, controls who have been involved in occupations with exposure to wood smoke or resided close to charcoal kilns were also excluded from the study.

A brief description of the setting

Charcoal manufacturing in Sapele is developing; so far no industry or plant for charcoal making exists; however, groups of individuals have set up (a total of 12) kiln sites with several combustion units (kilns) at each location. A typical kiln site consists of several mounds of earth arranged in rows and most times, owned and operated by several people. It takes about 10–14 days to complete a production cycle which usually runs concurrently, but production at various kilns may be at different stages of completion. Kilns are usually sited far away from major roads and industrial areas. The actual distance of each kiln from the traders varied, however, each kiln was at least 2 km from the traders.

Sample size and sampling technique

A minimum sample size of 276 (138 each group) was calculated with a formula for difference in proportions between two groups (prevalence of a cough among the exposed (13.7%) and non-exposed (3.7%) populations in southwest Nigeria) with a power of 80% and α error of 5%.[18 19] All charcoal workers had to be included in this study and an exact number of controls was selected with a simple random technique from among traders in Sapele. A table of random numbers was applied to weekly preselected 5–10 shops (between 1 and 150) from a market which was sited distantly from all charcoal kilns. With a clockwise sampling, only traders in the selected shops (a maximum of two or three traders in each shop) which satisfied the selection and matching criteria (5 years and 5 cm ranges were allowed for age and height, respectively, while sex had to be the same) were recruited for the study. Non-consenting traders were excluded from the study and substituted with other traders.

Ethical consideration

Written informed consent was given by each study participant and verbal permission was taken from the operators of charcoaling sites. Utmost confidentiality was maintained during the entire study period and participation in the study was entirely voluntary.

Data collection

A particulate matter air sampler which employs infrared electromagnetic radiation to detect airborne particles by light scattering (handheld air tester model CW-HAT 200 manufactured by Chinaway, China) measured air concentration of particulate matter at the kiln sites during periods of combustion and at fixed points close to the kilns, specifically over each earth kiln and the interlacing spaces, under the shades where workers rest and at the points where wood is offloaded from trucks. As particles traverse the sensing volume, they scatter Infrared light at a forward angle of 45–90 °. The amount of scattered light directly relates to particulate concentration and is expressed in micrograms per cubic metre (µg/m^3). With a precision of ±0.02 µg/m^3 and an accuracy of ±10%, the instrument operates under a temperature range of 5–45^{o}C, relative humidity of <90% and sampling time of 60 s. An hourly reading was taken for a period of 3 hours at each site, and the highest reading was recorded. This was repeated daily for 3 days irrespective of the phase of charcoal production and the average taken and recorded.

In addition, a non-directional air sampling was performed 100 m and 500 m away (two distant sampling stations) from the nearest kiln, at all 12 sites, to reflect ambient air concentrations in the immediate surroundings of charcoaling sites and in other areas with regular human activities. The concentration of the particulate matter within the environment was displayed on the monitor. Gases were measured with environmental sensor kits Z-1300(SO_2), Z-900(H_2S), Z-1200(O_3), Z-700(NO) and Z-1500(NH_3) manufactured by Environmental Sensors, Boca Raton, Florida, USA. Air quality index was calculated using one of the criteria air pollutants, $PM_{2.5}$ because it is a pollutant majorly derived from combustion of wood.[20]

Spirometric measurements were taken using a portable micro-GP spirometer (Micro Medical, Kent, UK) in compliance with the American Thoracic Society and European Respiratory Society Joint Task Force Guidelines on spirometry.[21] Actual values of peak expiratory flow rate (PEFR), forced expiratory volume in the first second (FEV_1), forced vital capacity (FVC) and FEV_1/FVC ratio (FEV_1/FVC) were measured as participants performed spirometric manoeuvres while predicted values were automatically displayed on the device after imputing their individual age, sex and height. Predicted lung function indices were modified by 12% (estimated for Africans) based on European Respiratory Society Standardised Lung Function Testing.[21] Spirometry was done with participants sitting in an upright position, and a full and deep inspiration followed immediately with a forceful and continuous expiration (for at least 6 s) into the mouthpiece. Several attempts were allowed per person and the best performance was recorded. Participants were preinformed about the procedure so that they had not smoked nor eaten a heavy meal 1–2 hours prior to the procedure.

A prevalidated questionnaire[22] was administered by the researchers to obtain information on only current respiratory symptoms. Respiratory symptoms were defined by the following criteria: *chronic cough*—cough up to 3 months; *productive cough*—expectoration up to 3 weeks; *breathlessness*—shortness of breath when walking with people of the same age on level ground or up a slight hill; *chest tightness*—feeling tight in the chest on the first day back at work on more than 50% of occasions and/or on other days too; *wheeze*—subjects or others nearby hearing a whistling sound when the subject is breathing; *nasal discharge*—runny nose.

An observational checklist adapted from combustible wood dust mitigation and a control checklist were used to conduct a walk-through survey of all the sites.

Outcome variables

The primary outcome measure was the prevalence of respiratory symptoms (chronic cough, productive cough, breathlessness, wheeze, chest tightness, nasal discharge) among charcoal workers while secondary outcome included air concentration of particulate matter and other pollutants (ammonia, sulphur dioxide, nitric oxide, ozone and hydrogen sulphide), lung function indices and hazard control practices among charcoal workers at all charcoal sites. Potential confounders of respiratory symptoms were age, smoking and domestic biomass use while lung function could be affected by age, sex and height. The exposure of interest in this study was occupational exposure to wood smoke from charcoal production.

Data analysis

All collected data were entered into the spreadsheet of Statistical Package for Social Sciences (SPSS) V.22 (IBM Corp, Armonk, New York, USA) for analysis. The concentration of air pollutants was expressed as mean±SD, median and range. A one-way analysis of variance (ANOVA) was applied to assess the difference between means. Prevalence of respiratory symptoms was presented as percentages. McNemar's test and ORs were applied to examine the associations of respiratory symptoms with occupational exposure and their magnitude, respectively. Paired *t*-test was applied to assess the difference in mean height between the two study groups. Biomass use and smoking of cigarettes were adjusted for using binary logistic regression to control for any residual confounding effect these parameters might have after matching as they are known to increase the risk of respiratory symptoms. Student's t-test was applied to deduce mean differences in lung function indices between charcoal workers and their controls while multivariate analysis was used to adjust for the effect of educational level and biomass among non-smoking participants' lung function indices. The level of statistical significance was set at value of $p<0.05$ for ANOVA, McNemar's test, χ^2 test and paired *t*-test and adjusted with a Bonferroni correction.

Patient and public involvement

The results of the study would be communicated verbally to study participants at all charcoal kiln sites and they will be educated on safe, affordable and sustainable hazard control practices. Patients and the public were not involved in this study.

RESULTS

The response rate among charcoal workers was 98.6% (148/150) as two of them declined to participate in the study; 148 controls were also recruited. The ratio of charcoal workers to controls was 1:1. Nearly two-thirds (62.8%) of all respondents were women. Controls had a significantly higher secondary education than charcoal workers, though illiteracy and tertiary education were virtually the same in both groups (see table 1).

The majority (83.3%) of the sites had PM_{10} and $PM_{2.5}$ values five times higher than the WHO standard; and mean concentrations of $PM_{2.5}$ and PM_{10}, 146.6 µg/m^3 and 359.3 µg/m^3, respectively, were over five and six times the WHO standard. Average concentrations of ozone,

Table 1 Sociodemographic characteristics of respondents

Variables	Charcoal workers (n=148) n (%)	Control group (n=148) n (%)	P value for McNemar's test
Age groups (years)			
11–30	55 (37.2)	58 (39.2)	
31–50	58 (39.2)	52 (35.1)	0.77
>50	35 (23.6)	38 (25.7)	
Gender			
Male	55 (37.2)	55 (37.2)	
Female	93 (62.8)	93 (62.8)	1.00
Educational status			
None	18 (12.2)	20 (13.5)	
Primary	61 (41.2)	20 (13.5)	<0.01
Secondary	58 (39.2)	96 (64.9)	
Tertiary	11 (7.4)	12 (8.1)	
Domestic biomass use	103 (69.6)	5 (3.4)	<0.01
Cigarette smokers	14 (9.5)	4 (2.7)	0.02
Height (m)	1.63±0.09	1.64±0.08	0.07*

*p value for the paired t-test.

hydrogen sulphide and ammonia at charcoal production sites were significantly higher than at 100 m and 500 m away from the sites. However, nitric oxide was highest at 100 m away from the sites. The average concentration of sulphur dioxide was higher than the WHO standard of 20 µg/m^3. Air quality at a third (33.3%) of all the sites was very unhealthy and that in one of the sites was highly hazardous, although two sites had moderately healthy air quality. The mean differences in concentrations of air pollutants between the kiln sites 100 m away and 500 m away (at each site and at the two distances) were significant for all pollutants, except for sulfur dioxide, and hydrogen sulfide (see table 2). The prevalence of chronic cough and chest tightness among charcoal workers was 9.5% and 8.8%, respectively. Charcoal workers had higher odds of productive cough, wheeze, breathlessness and nasal discharge; however, after adjusting for age, biomass use and cigarette smoking only the OR for wheeze was significant (OR 4.22; CI 1.37 to 12.99). The dose-response relationship between site-based exposure levels to air pollutants and the prevalence of respiratory symptoms among charcoal workers was significant for all symptoms except chest tightness (p=0.167). The association between biomass use and prevalence of respiratory symptoms was not statistically significant (see table 3). Predicted values of all pulmonary indices were higher among controls than charcoal workers; however, the difference was not significant. Among non-smokers, the mean values of FEV_1 (2.01±0.83 L vs 2.23±0.73 L; p=0.013) and FVC (2.41±0.94 L vs 2.93±1.02 L; p<0.001) were lower among charcoal workers; conversely the FEV_1/FVC ratio (83.46%±11.78% vs 77.78±10.26%; p<0.001) and PEFR (239.04±101.15 L/min vs 238.73±102.14 L/min; p=0.980) were higher for workers; but the difference was not significant for PEFR (see table 4).

More than half (57.1%) of all workers were aware of personal protective equipment or devices (PPE/PPD), although only a minority (3.4%) reported using them. Use of face mask or nose mask as a means of protection against inhaling smoke was mentioned by majority 68/84 (80.9%) of the respondents who knew about PPDs. A negligible fraction (2.0%) of charcoal workers claimed they used PPEs when they felt like it, and a smaller (1.4%) proportion used PPDs when they were available. A minority (2.7%) of workers maintained they have been educated on the use of PPE by a health worker. All the sites were outdoors with natural ventilation though there was neither local exhaust ventilation nor hood connected to a vacuum system in any of the workstations. No sanitary facility was seen at the sites. Only three of the sites had canteens, though at nine (75%) of the sites lunch was eaten at spots with minimal exposure to wood smoke. Nonetheless, no educational material was displayed at any site and just one kiln site had an insignificant percentage (1.4%) of workers with hand gloves while working. No worker was seen wearing respirators, goggles, hard hat or coverall. Furthermore, there was no fire extinguisher, first aid treatment kit or any medical unit at the kiln sites (see table 5).

DISCUSSION

This study revealed that mean values of respirable (PM_{10}) and inhalable ($PM_{2.5}$) particulate matter were about six and seven times the WHO standard. (10) This finding elucidates the magnitude of the hazard from charcoal making

Table 2 Concentrations (µg/m^3) of air pollutants at kiln sites

Kiln site	$PM_{2.5}$	PM_{10}	Sulfur dioxide	Hydrogen sulfide	Nitrogen monoxide	Ozone	Ammonia	AQI	Health concern (20)
A	226	474	34.0	25.0	36.0	20.0	108.0	276	Very unhealthy
B	72	180	22.0	30.0	26.0	30.0	36.0	160	Unhealthy
C	46	20	21.0	35.0	31.0	28.0	32.0	127	Unhealthy for sensitive
D	117	269	25.0	25.0	17.0	17.0	23.0	183	Unhealthy
E	171	888	76.0	75.0	73.0	76.0	75.0	221	Very unhealthy
F	72	185	36.0	34.0	27.0	43.0	44.0	160	Unhealthy
G	23	50	22.0	24.0	21.0	26.0	23.0	74	Moderate
H	23	52	27.0	24.0	26.0	25.0	28.0	74	Moderate
I	116	243	26.0	28.0	26.0	32.0	27.0	182	Unhealthy
J	507	1064	32.0	34.0	22.0	33.0	22.0	>AQI	Highly hazardous
K	221	508	43.0	43.0	43.0	43.0	31.0	271	Very unhealthy
L	165	379	20.0	43.0	34.0	30.0	36.0	215	Very unhealthy
Mean at all sites*	146.6	359.3	32.0	35.0	33.6	23.1	40.4	198	Unhealthy
Mean 100 m away†	0.0	0.0	21.9	22.3	22.3	31.8	21.0	0	Good
Mean 500 m away‡	0.0	0.0	35.5	19.4	18.3	18.9	17.3	0	Good
P value for ANOVA	<0.001	<0.001	0.948	0.596	0.012	0.025	0.003	–	–

One way analysis of variance for mean differences in the concentration of air pollutants between: all sites*, within 100 m† and 500 m away‡ from the sites.
WHO standard $PM_{2.5}$: 25 µg/m^3; PM_{10}: 50 µg/m^3; SO_2: 20 µg/m^3; O_3:100 µg/m^3.
AQI, Air Quality Index; ANOVA, analysis of variance.

and is in keeping with reports from Mexico, Malawi and Tanzania.[23–25] In addition, the average concentration of sulphur dioxide was higher than the WHO standard of 20 µg/m^3, and most sites had higher levels. Nevertheless, the average concentration of this pollutant at distances 500 m away from the closest charcoal kiln site appeared higher than that from the charcoal production sites. This is likely due to the simultaneous emission of sulphur dioxide from other combustion sources including bush burning, vehicle exhaust, and so on. Similarly, nitric oxide, a probable precursor of nitrogen dioxide was highest at 100 m away from the sites. Thus, it was not unlikely that wind could have disseminated air pollutants away from the kiln sites and potentially spread it to residential areas.

Ammonia commonly accompanies high levels of particulate matter,[26] and unlike nitric oxide it was highest at the kiln sites. This indicates that charcoal production is a major source of this pollutant and further demonstrates the enormity of air pollution from charcoal production, especially as more than half of all air pollutants assessed were significantly higher at the production sites than at 100 m and 500 m away. Consequently, to avoid long-term complications of inhaling contaminated air among charcoal workers, improved devices which potentially emit less wood smoke, for instance, low-cost retort and Casamance kilns used in other developing nations for charcoal production can replace earth kilns.

Nasal discharge was the the most common respiratory symptom and was reported in slightly over a third (34.9%) of charcoal workers. This prevalence is comparable with 35.8% and 37.0% reported among individuals exposed to wood smoke from previous studies conducted in Brazil and Kebbi State, Nigeria, respectively.[14 15] This similarity suggests that nasal discharge, although a symptom of the upper airways, is a common respiratory symptom of workers exposed to wood smoke. However, they may also have other nasal symptoms such as sneezing and nasal itching, often manifesting during work hours and thus suggestive of occupational rhinitis.[27]

In this study, about a tenth (9.5%) of the workers had chronic cough. However, slightly higher and lower prevalences have been recorded from previous studies conducted in Namibia and Brazil, where 13% and 7.5%, respectively, of the study participants had chronic cough.[15 16] The higher prevalence of chronic cough may be due to the use of less advanced devices, especially the traditional earth kilns which are fraught with emitting immensely profuse wood smoke for charcoal production in developing nations. Thus, charcoal workers in Third World nations were probably exposed to higher levels of wood smoke.

Table 3 Prevalence of respiratory symptoms among respondents

Symptoms	Charcoal workers n (%)	Controls n (%)	OR* Crude OR	95% CI†	Adjusted OR‡	95% CI§
Chronic cough	14 (9.5)	0 (0.0)	–	–	–	–
Productive cough	20 (13.5)	5 (3.6)	8.50	1.96–36.79	2.45	0.30–20.25
Wheeze	13 (8.8)	8 (5.4)	2.67	0.70–10.05	4.22	1.37–12.99
Breathlessness	29 (19.6)	20 (13.5)	1.90	0.88–4.09	2.19	0.95–5.05
Chest tightness	13 (8.8)	0 (0.0)	–	–	–	–
Nasal discharge	51 (34.9)	24 (16.2)	2.33	1.40–3.89	1.41	0.61–3.27

Site-based dose-response relationship between level of air pollutants and prevalence of respiratory symptoms among charcoal workers
Frequency (%)

Kiln site	$PM_{2.5}$	No. of Charcoal workers per site (148)	Chest tightness (13)	Chronic cough (14)	Dyspnoea (29)	Productive cough (20)	Wheeze (13)	Nasal discharge (51)
A	226	17 (11.5)	1 (7.7)	5 (35.7)	0 (0.0)	2 (10.0)	3 (23.1)	12 (23.5)
B	72	10 (6.7)	0 (0.0)	0 (0.0)	2 (6.9)	1 (5.0)	0 (0.0)	0 (0.0)
C	46	12 (8.1)	0 (0.0)	0 (0.0)	1 (3.4)	0 (0.0)	0 (0.0)	0 (0.0)
D	117	15 (10.1)	1 (7.7)	0 (0.0)	5 (17.2)	1 (5.0)	3 (23.1)	3 (5.9)
E	171	11 (7.4)	3 (23.1)	0 (0.0)	1 (3.4)	3 (15.0)	0 (0.0)	5 (9.8)
F	72	5 (3.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (2.0)
G	23	11 (7.4)	0 (0.0)	0 (0.0)	2 (6.9)	0 (0.0)	0 (0.0)	0 (0.0)
H	23	8 (5.4)	0 (0.0)	0 (0.0)	2 (6.9)	0 (0.0)	0 (0.0)	0 (0.0)
I	116	9 (6.1)	1 (7.7)	1 (7.1)	1 (3.4)	0 (0.0)	0 (0.0)	3 (5.9)
J	507	28 (18.9)	4 (30.8)	8 (57.2)	15 (51.7)	8 (40.0)	5 (38.4)	22 (43.1)
K	221	11 (7.4)	2 (15.4)	0 (0.0)	0 (0.0)	3 (15.0)	2 (15.4)	4 (7.8)
L	165	11 (7.4)	1 (7.7)	0 (0.0)	0 (0.0)	2 (10.0)	0 (0.0)	1 (2.0)
P¶ value for dose-response relationship			0.167	0.001	<0.001	0.03	0.039	<0.001

*The OR for matched pairs.
†CI of crude OR.
‡Adjusted for cigarette smoking and biomass exposure with logistic regression.
§CI of adjusted OR.
¶LR χ^2.

The prevalence of a productive cough was 13.5% and comparable to a prevalence of 12.7% recorded from a study conducted in Mexico.[23] This prolonged expectoration might be due to a defect in the mucociliary function of the respiratory system,[28] which would increase susceptibility to infection. Similarly, components of wood smoke such as formaldehyde have been known to hamper mucociliary clearance of microorganisms,[29 30] thus, expectoration among these workers may not be unrelated to their exposure to wood smoke.

The prevalence of self-reported wheeze among charcoal workers, 8.8% was comparable to 8.7% and 7.5% reported from previous studies conducted in Brazil and Ekiti State, Nigeria, respectively.[15 19] However, it is lower than 12% and 16.6% reported from other studies conducted in Kebbi State and Edo State, Nigeria, respectively.[14 31] The higher prevalence of wheeze reported from these studies may be related to a longer exposure to wood smoke. Nevertheless, since wheezing is due to airflow resistance, some charcoal workers apparently had features of obstructive airway disease.

About a fifth (19.6%) of charcoal workers reported breathlessness. Earlier studies have reported similar prevalences of breathlessness, 18.7% and 17.8% in northern Nigeria and Nepal, respectively.[14 32] Their breathlessness may progress to affecting gaseous exchange in the alveoli and impair tissue metabolism due to accumulated carboxyhaemoglobin. Carboxyhaemoglobinaemia has been documented among charcoal workers.[33]

When compared with suitably matched controls the prevalence of most respiratory symptoms was higher among charcoal workers. Previous studies conducted in Mexico and Nigeria have recorded a predominance of respiratory symptoms in the exposed population.[14 19 23 31]

Table 4 Lung function indices: predicted values among all participants and actual values of non-smokers only

Pulmonary indices	Charcoal workers (n=148)	Controls (n=148)	Mean difference (a)	*t* test	95% *CI Lower limit	95% *CI Upper limit
All participants†						
FEV_1(L)	2.65±0.69	2.78±0.67	−0.13	1.64	−0.29	0.03
FVC (L)	3.15±0.81	3.28±0.77	−0.13	1.42	−0.31	0.05
FEV_1/FVC (%)	84.13±6.00	84.75±3.08	−0.62	1.12	−1.71	0.47
PEFR (L/min)	439.00±94.00	460.00±101.00	−21.00	1.85	−43.32	1.32
	Only non-smoking participants		**Effect size: difference of mean indices**		**Adjusted 95% *CI**	
	n=134	**n=144**	**Crude**	**Adjusted‡**	**Lower**	**Upper**
FEV_1 (L)	2.01±0.83	2.23±0.73	−0.22	−0.22	−0.43	−0.01
FVC (L)	2.41±0.94	2.93±1.02	−0.52	−0.50	−0.76	−0.24
FEV_1/FVC (%)	83.46±11.78	77.78±10.26	5.68	6.07	3.07	9.07
PEFR (L/min)	239.04±101.15	238.73±102.14	0.31	5.72	−21.83	33.26

*CI of mean differences.
†Only predicted values for age, sex and height represented to show comparability between charcoal workers and controls.
‡Adjusted for education and biomass use with multivariate analysis.
FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; PEFR, peak expiratory flow rate.

After adjusting for tobacco smoking and biomass use this study showed that charcoal workers were four times as likely as controls to have wheeze, and more than twice as likely to have a productive cough and breathlessness. However, the association of exposure to wood smoke and respiratory symptoms was only significant for wheeze. The confounding effects of biomass and tobacco smoke on respiratory symptoms are apparent since they differed enormously between the two groups and the OR for a productive cough was significantly higher before adjusting for them. Nevertheless, the current study may have been underpowered to detect a statistically significant difference for a productive cough and breathlessness.

On the other hand, chronic cough and chest tightness were totally absent among controls, and this corroborates the finding that exposure to wood smoke even for a short period can significantly worsen respiratory symptoms among charcoal workers.[34] The site-based levels of air pollutants dose-response relationship was significant for almost all respiratory symptoms with a higher prevalence for sites with worse air quality. However, personal exposure levels to air pollutants were not assessed for each charcoal worker, thus further studies may be required to establish the causal individual dose-response relationship among these workers.

Both study groups were comparable in their predicted lung function indices. This indicates a similarity in characteristics which could affect lung capacities, however, the deleterious effects of wood smoke are substantiated by lower FVC and FEV_1 among charcoal workers in this study. A similar study has documented poorer lung capacities in groups exposed to wood smoke.[35] Nonetheless, a higher forced expiratory ratio was recorded among non-smoking charcoal workers and, probably due to a disproportionate reduction in FVC compared with FEV_1 (ie, there may potentially be more of an effect on restrictive lung disease).

Proper and consistent use of PPE/PPD is one of the adjunct measures for the control of hazard in the workplace and it is essential for preventing hazards that cannot be totally eliminated. A low level of PPE utilisation was recorded in this study and is corroborated by a previous study conducted in Brazil where 92.5% of workers did not use a face mask.[15] The dearth of training could account for the poor usage of PPDs as only 1 in 40 workers had been educated on the consistent use of PPE. Regular training of charcoal workers could wield a positive influence on their practice since interventions to increase workplace safety via hands-on training have yielded a positive outcome in other parts of the world.[36] In addition, the willingness of operators of charcoal kiln sites to provide as well as enforce the consistent use of PPDs is an area that would need consolidation. Equally, the safety performance of workers including the use of safety equipment such as PPDs has been documented to have a positive relationship with functional health and safety management systems in the workplace.[37]

Measures for isolating wood smoke at the source were absent at all sites; thus workers probably breathed in wood smoke from the burning kilns. On the contrary, earlier studies have demonstrated that local exhaust ventilation can efficiently purify contaminated air, and its consistent application has effectively decreased workplace hazards below the threshold limit value.[38 39] In addition, health

Table 5 Hazard control practices among charcoal workers

Reported practices	Categories	Frequency (%)	Observed practices	N (%)
Awareness of PPEs	Aware	84 (57.1)	Sites with natural ventilation (outdoors)	12 (100.0)
	Not aware	64 (42.9)	Sites with functional hoods connected to vacuum system/local exhaust ventilation	0 (0.0)
	Total	148 (100.0)	Sites with sanitary facilities, fire extinguisher, first aid treatment kit or medical unit	0 (0.0)
			Sites with welfare facilities such as canteen	3 (25.0)
Types of PPEs workers are aware of	Face mask	68 (80.9)	Sites with areas for lunch without exposure to toxic materials or other health hazards	9 (75.0)
	Hand gloves	5 (5.9)	Sites with an adequate display of education materials	0 (0.0)
	Coverall	3 (3.6)	Sites with provided protective goggles worn where there is any danger of flying particles or corrosive materials	0 (0.0)
	Hard hat/helmet	4 (4.8)		
	Safety boot	4 (4.8)	Are protective gloves provided and worn against cuts or burns?	1 (8.3)
Use of PPE	Used PPEs	5 (3.4)	Are hard hats provided and worn where the danger of falling objects exists?	0 (0.0)
	Did not use PPEs	143 (96.6)	Sites with approved respirators provided for regular or emergency use where needed	0 (0.0)
	Total	148 (100.0)	Foot protection worn against the risk of foot injuries from hot, corrosive, poisonous substances, falling objects, crushing or penetrating actions	0 (0.0)
How often do you use PPEs?	When I feel like	3 (2.0)	Maintenance of protective equipment in a sanitary condition and ready for use	0 (0.0)
	If/when available	2 (1.4)		
Number of workers who have received training on the use PPEs		4 (2.7)		0 (0.0)
Number of workers observed using respirators, protective goggles, coveralls or boots at all sites		0 (0.0)		
Number of workers observed using hand gloves at all sites		2 (1.4)		

PPE, personal protective equipment.

and safety information is indispensable for ensuring a safe work environment and developing educational materials for workers can reduce the risk of work-related injuries;[40] nevertheless, no educational material was displayed at any of the sites.

The enormous occupational hazard among charcoal workers and the gaps in their work-related safety practices suggest that pertinent hazard control measures have to be instituted to forestall a permanent damage to their lung health. Thus, the foregoing reasons necessitate a strengthening of occupational health services in resource-poor occupational settings as the observed lacunae in the health and safety practices in this study are somewhat linked to the work location. More so, the findings of the study, despite its limitations, can be extrapolated to informal charcoal worker groups in low-income and middle-income countries, mainly for its congruence with some previous studies.

The design of this study precluded eliciting the incidence of wood smoke–associated respiratory diseases such as asthma and COPD. Furthermore, individualised exposure levels to air pollutants were not assessed in this study, thus, highlighting an additional limitation of this study. Nonetheless, the apparent drawbacks of this study provide opportunities for future research among charcoal workers.

CONCLUSION

High concentrations of air pollutants at kiln sites exceeded WHO standards. The prevalence of chronic cough, chest tightness and wheeze was significantly higher

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among workers. Nevertheless, a significant chasm in hazard control practices was observed at all kiln sites; thus adopting improved devices with minimal or moderate smoke emission and appropriate hazard control practices would be necessary for their long-term health benefit.

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