Exposure to air pollution and lung function among cassava grits (Gari) processors in Ghana.

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DECLARATION

I, OMOLOLA OYINKAN ADESHINA, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

[redacted]

Date: JANUARY 24, 2024

ABSTRACT

Background: Smoke from biomass combustion leads to around 3.2 million premature deaths annually, with a proportion of these deaths attributable to exposure to cook smoke during economic activities. One such economic activity that uses biomass fuel is cassava grits (gari) processing. Gari is a staple food produced from grated and fermented cassava in countries such as Ghana. The cookstoves used in the gari processing industry emit biomass fumes that expose workers and their children to pollutants such as fine particles diameter less than 2.5 micrometres ($PM_{2.5}$) and carbon monoxide (CO), but little is known about the exposure levels for workers and the resulting health effects in this setting.

Aim: The aim of this research was to quantify the levels of exposure to $PM_{2.5}$ and CO among the cassava grits processors performing cookstove activities in the gari industry (workers) in the Bono East region of Ghana, and to investigate associations between these exposures and respiratory health condition among the workers and a comparison group.

Methods: A cross-sectional observational study was conducted among 97 workers and 97 comparisons using portable exposure monitoring devices to measure individual $PM_{2.5}$ and CO levels for 48-hours and a hand-held spirometer to measure lung function parameters in the Kintampo South and Techiman North Districts in the Bono East region of Ghana. $PM_{2.5}$ and CO exposure was characterised by minute-averages for each study participant with three activity-hours categories: gari-working hours, active home hours (including home cooking and burning activities) and non-active home hours. Pulmonary function tests (FEV_1, FVC, FEV_1/FVC and $FEF_{25-75\%}$) were performed at the end of the 48-hour period and self-reported respiratory symptoms were collected by standardized questionnaires. Associations between $PM_{2.5}$ and CO exposure and lung function and subjective respiratory symptoms were examined by a multi-regression model with adjustment for covariates including home cooking behaviours and education.

Results: Study participants were exposed to very high levels of $PM_{2.5}$ and CO: median (IQR) hourly-average exposure levels over 48 hours for workers and community comparisons were 76.2 (52.3-118.5) and 33.7 (19.7-52.5) μg/m^3 $PM_{2.5}$ and 3.1 (2.1-5.9) and 1.6 (1.5-1.8) ppm for CO, respectively. $PM_{2.5}$ and CO exposure levels were also generally higher for the workers compared to the community comparisons during active or non-active home-hours. The analysis of associations between personal exposure to $PM_{2.5}$ or CO and lung function suggested little evidence of associations between IQR change in $PM_{2.5}$ and CO exposure and change in lung function parameters. There was evidence suggesting $PM_{2.5}$ and CO exposure may affect detrimentally some lung functions among the comparison group, but not for the worker group. There was a significant difference in FVC% between workers and comparisons, an IQR change in minute-mean $PM_{2.5}$

exposure level resulted in 1.53% (-0.88%, 3.94%) in workers vs -3.88% (-9.12%, 1.36%) difference in comparisons and 0.69% (-1.08%, 2.46%) in workers and -5.04% (-9.36%, -0.73%) in comparisons for CO. Moreover, this study found an increased risk of Restrictive pattern of pulmonary function abnormality in the comparison group compared to the worker group due to CO exposure. This finding was different in the assessment of self-reported respiratory symptoms, with the comparison group generally healthier than the worker group.

Conclusion: This study suggests that workers in Bono East Region of Ghana are exposed to $PM_{2.5}$ and CO levels that are nearly twice as high as those experienced by comparisons in the same communities. The assessment of self-reported respiratory symptoms revealed generally better respiratory health in the comparison group compared to the worker group. However, there was little evidence of an association between $PM_{2.5}$ or CO exposure and lung function despite higher exposures in the worker group. Further studies are needed to assess the direct effects of air pollution exposure due to gari processing in workers employed in this industry.

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INTEGRATING STATEMENT

This integrating statement aims to reflect on my experiences and personal development through the three components of the DrPH programme: (1) The taught component comprising of two courses namely, Evidence-based Public Health policy and Practice (EBPHP), and Understanding Leadership, Management & Organisations (ULMO); (2) Research I: an Organisational and/or Policy Analysis (OPA) project; (3) Research II: thesis project.

I recall my desire to study Clinical Medicine all through my undergraduate studies was so strong until 2014 while discussing with fellow colleagues on how Public Health and Clinical Medicine operated in silos at the time, especially with implementation science. Fast forward, I became intrigued in understanding the need to play a role in bridging this gap and started looking into professional courses in this direction. Reflecting on the different course programs, I found the DrPH programme to be the most practical.

I undertook my taught component from September 2017 to December 2017. Prior to beginning the DrPH, I had limited knowledge on these two components. My specific interest for the DrPH course was to acquire policy implementation and organisational leadership skills within the health sector. The ULMO course equipped me with the theoretical knowledge to reflect and improve on my own leadership and management skills. The EBPHP course equipped me with practical skills on moving evidence-based research into policy, and through various sessions the course instructors held with expert leaders in the field, I was opportune to equally learn how decision makers implement policies on a global scale.

I undertook my OPA in the Kintampo Health Research Centre of the Ghana Health Service in Ghana where I was attached for seven months. My OPA project focused on the barriers and facilitators to the nationwide implementation of the RTS,S/AS01E malaria vaccine in Ghana. While conducting the OPA research, I met with various internal and external stakeholders to the Ghana Health Service involved in policy decision making. My meetings with these stakeholders gave me the opportunity to learn from their thought processes involved in policy implementation. The OPA research project resulted in a publication with the Health Policy and Planning journal co-authored with my supervisors and policy implementation experts,

My thesis did not build on the OPA component. Prior to starting the DrPH course, I had learned about workers in the cassava grits industry, mostly women being exposed to cook smoke while processing cassava grits (gari). From my first knowledge of the working conditions of this worker group, I was interested in learning about the measure of exposure to particulate matter and carbon monoxide these workers are faced with because from childhood, gari has been a staple food in my family home. However, I was never aware of the working conditions of workers in the industry until some years ago when I was opportune to engage with this worker group.

My thesis research was focused on quantifying the levels of exposure to $PM_{2.5}$ and CO among the workers in the Bono East region of Ghana, and to investigate associations between these exposures and respiratory health condition among the workers compared to the community comparisons. This research project strengthened my quantitative research conducting skills. Whilst conducting the thesis research, I was privileged to work with my supervisors and other air pollution experts with experience in various country regions to investigate the exposure patterns in the workers.

To conclude, my experience during the DrPH, especially working with my supervisors and other leading experts in various health domains in the course of the different components of the DrPH has provided guidance to shaping my Public Health research skills and improved my knowledge on solving and addressing complex Public Health challenges.

LIST OF ABBREVIATIONS

BMI	Body Mass Index
CO	Carbon monoxide
COPD	Chronic Obstructive Pulmonary Disease
DALY	Disability-Adjusted Life Years
FEV_1	Maximum exhalation of air in the first second
$FEF_{25-75\%}$	Forced Expiratory Flow at 25% and 75% of the pulmonary volume
FVC	Forced Vital Capacity
GBD	Global Burden of Disease
HAP	Household Air Pollution
$PM_{2.5}$	Particulate matter, fine particles of diameter less than 2.5 µm
WHO	World Health Organization

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CHAPTER 1: BACKGROUND

1. Air pollution

1.1. Air pollution and health

Air pollution is atmospheric contamination due to biological, chemical or physical agents that include particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (O_3) [1]. Common sources include traffic, industrial processing sites, and household fuels [1]. The World Health Organization (WHO) estimates that around 7 million deaths each year occur globally due to the combined effects of ambient (outdoor) air pollution and household air pollution (HAP) [2], with around 1 million deaths in the Africa region (Figure 1) [3].

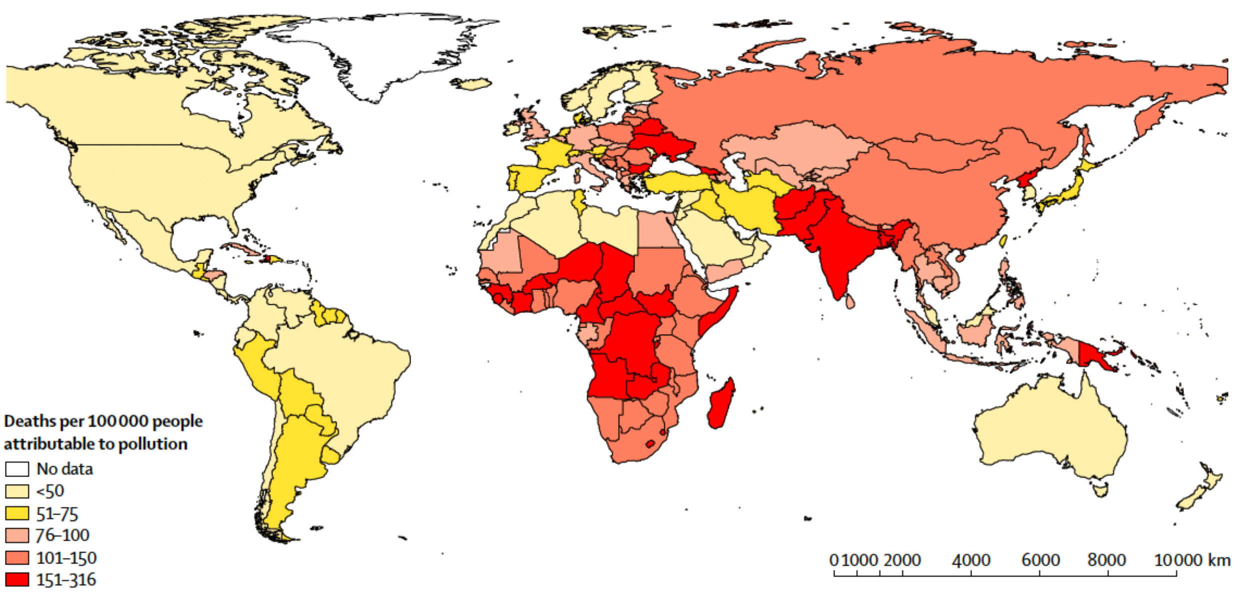


Figure 1: Pollution deaths per 100 000 people, 2015 **Source:** The Lancet, 2017 [4]; GBD, 2016 [5]

Of the global deaths, ambient air pollution is thought to cause roughly 4.2 million with an estimated 3.2 million from HAP annually [2]. The causes of these air pollution-related deaths include stroke, respiratory diseases, including chronic obstructive pulmonary disease (COPD), lung cancer, cardiovascular diseases and negative birth outcomes [4]. The Global Burden of Disease (GBD) study estimated in 2019 that $PM_{2.5}$ air pollution was also responsible for 13% of all Disability-Adjusted Life Years (DALYs) globally, contributing much more to global health burdens than water contamination or lead exposure for example (Figure 2) [5, 6].

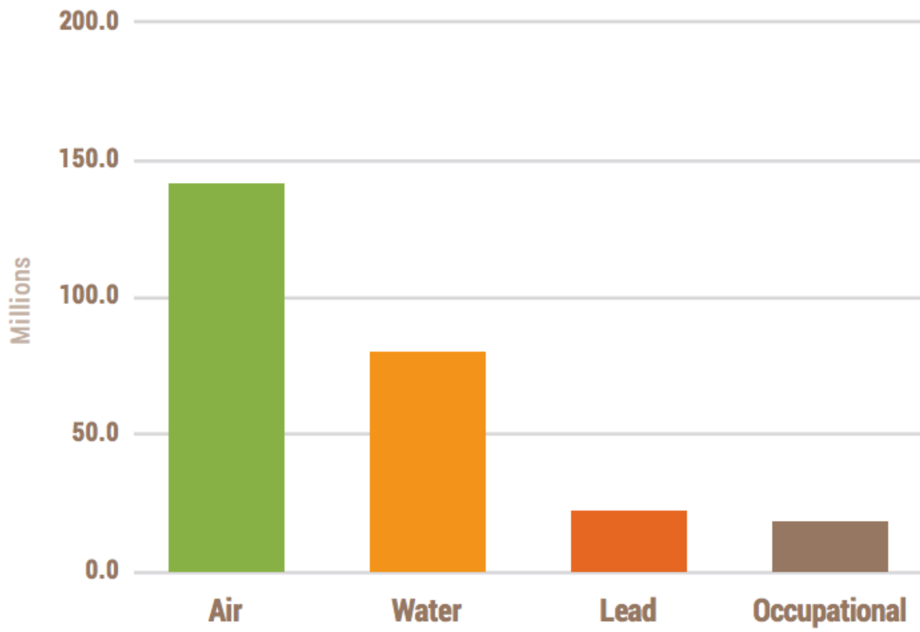


Figure 2: Global DALY'S attributable to $PM_{2.5}$ air pollution per million, 2019 [7, 8]

The health impacts from air pollutants such as PM, CO, NO_2, SO_2 and O_3 include health outcomes related to the effects of both short-term and long-term exposure [9, 10]. Symptoms of short-term air pollution exposure range from headaches, dizziness, coughing, wheezing, and breathing difficulties to more serious impacts including asthma exacerbation pneumonia and bronchitis. Studies on long-term exposure have found positive associations with outcomes including cardiovascular diseases, negative birth outcomes and mortality [11]. Table 1 shows the proportion of global deaths in Africa from all air pollution, to ambient $PM_{2.5}$ pollution, to HAP, and ambient ozone pollution [12].

Table 1: Estimated air pollution deaths in Africa and globally, 2019

	Deaths attributable to air pollution (95% uncertainty interval)		**Proportion of global deaths in Africa**
	Africa	**Global**	
All air pollution	1.1 million (932 000 - 1.3 million)	6.7 million (5.9 million - 7.5 million)	16.3%
Ambient $PM_{2.5}$ pollution	383 419 (288 615 - 491 042)	4.1 million (3.4 million - 4.8 million)	9.3%
Household air pollution	697 000 (526 000 - 879 000)	2.3 million (1.6 million - 3.1 million)	30.3%
Ambient ozone pollution	11 230 (4800 - 18 300)	365 000 (175 000 -564 000)	3.1%

Source: The Lancet, 2021[12]

The burden of air pollution is higher in developing countries than the developed countries, in part because 'clean' cooking fuels (such as electricity and liquefied petroleum gas) have not yet been fully adopted by the population. Roughly half of the global population (about 3 billion), mainly in low- and middle-income countries, lack access to clean cooking fuels [13]. The use of non-clean cooking fuels, such as biomass fuels in the form of wood and coal, in households contributes to both indoor and outdoor air pollution. Moreover, more women than men bear the effect of these polluting cooking practices because they are the primary users of non-clean cookstoves [14]. There are also disparities in socio-economic strata groups and between rural and urban areas, with non-clean fuels used primarily by lower income groups. Industrialization and urbanization in compacted neighborhoods and cities have further contributed to poor air quality in many parts of the world [15].

1.1.1. Respiratory health effects

Air pollution exposure has been linked with a range of adverse respiratory health effects. According to the GBD study, in 2017, more than 170 million people globally were estimated to have COPD [16]. The most common risk factor for COPD was tobacco smoking, but evidence is growing for a range of other factors including air pollution exposure [17, 18]. Long-term exposure to air pollutants is now thought to significantly increase the risk of various pulmonary diseases and mortality due to lung cancer [19]. For example, the European Study of Cohorts for Air Pollution Effects (ESCAPE) has shown that even $PM_{2.5}$ levels lower than 25µg/m^3 are associated with adverse health effects (on lung cancer in the case of ESCAPE), suggesting there is likely to be no lower threshold for adverse health effects [20].

Short-term exposure has also been linked with a range of acute respiratory effects. Lung function assessments have found exposure to air pollutants to be a contributing factor to lung function abnormalities. These tests are used to assess if lung functionality is normal or if there are obstructive defects, or restrictive or mixed obstructive-restrictive patterns in the lungs [21]. An obstructive defect affects an individual's ability to exhale all air in the airways due to the narrowing of the lungs. An individual with a restrictive pattern will have difficulty in expanding their airways when inhaling, hence the amount of air inhaled is reduced [22]. A decrease in the maximum exhalation of air in the first second (FEV_1) has been found in both obstructive and restrictive diseases. A decrease in the maximum exhalation of air for the total duration of the lung function assessment (FVC) has been found in people with restrictive patterns [23].

1.1.2. Exposure to $PM_{2.5}$ and CO and health effects

Of the many different types of air pollutants that adversely affect health, the most commonly studied is particular matter (PM). There are, broadly, three classifications of PM: coarse particles of diameter up to

10 µm (PM_{10}), fine particles of diameter less than 2.5 µm ($PM_{2.5}$), and ultrafine particles of diameter less than 0.1 µm (UFP) [24]. Particulate matter derives from different sources but $PM_{0.1}$ is mainly from vehicle exhausts. Fine particles, $PM_{2.5}$, arise primarily from coal burning, industrial processes, and wood burning. Finally, coarse particles, PM_{10}, result primarily from road dust from motor vehicle transports, road construction, general construction, and industrial emissions [25]. Of the three, $PM_{2.5}$ and $PM_{0.1}$ are thought to have the more detrimental effects on health because their small size means they are able to penetrate deep into the lung tissues and blood stream [25]. In recent years, PM, particularly $PM_{2.5}$ has been studied in relation to both short-term and long-term exposures to air pollution due to its role in penetrating tissues of the lung [26]. Figure 3 shows the estimated range of ambient air pollution across the African region.

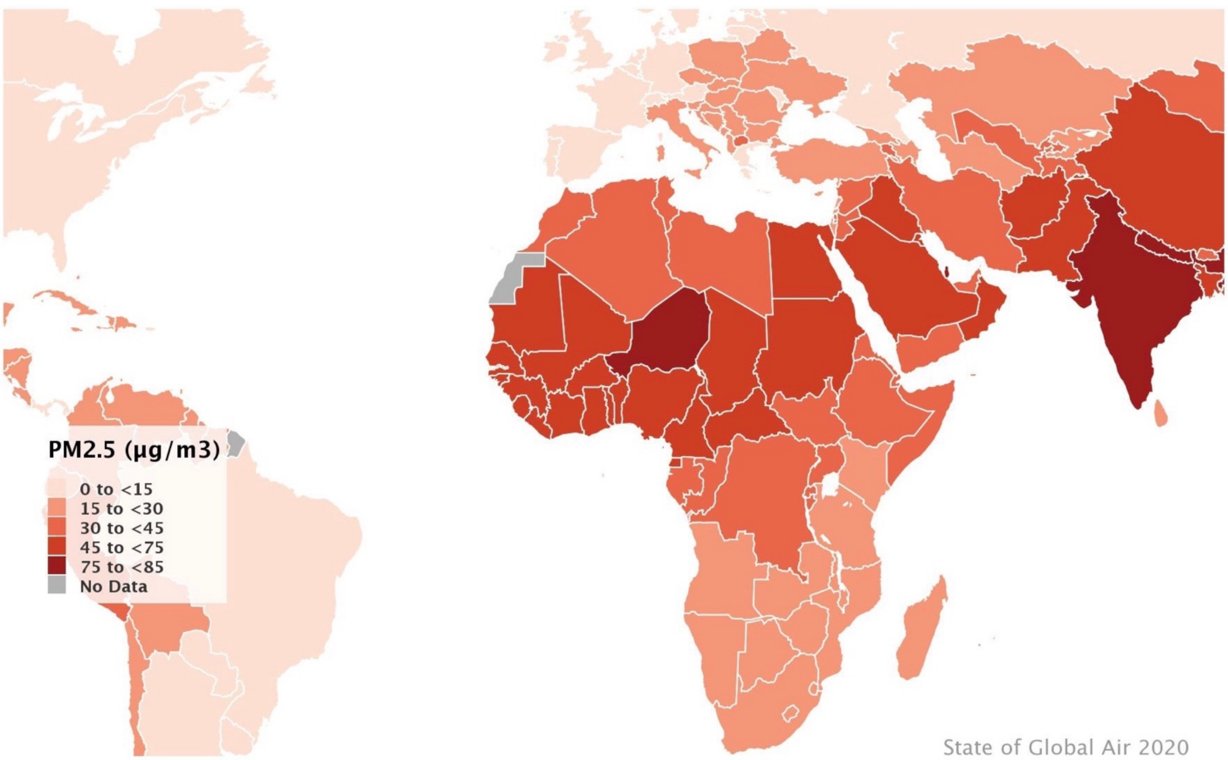


Figure 3: Map of Africa showing range of ambient air pollution **Source:** Health Effects Institute. 2020. State of Global Air 2020. Data source: Global Burden of Disease Study 2019. IHME, 2020 [27]

Carbon monoxide (CO) is a colorless, odorless, and tasteless gaseous substance, and inhalation of CO blocks oxygenation to cells, tissues and organs in the body [28, 29]. Exposure is known to cause dizziness, shortness of breath, blurred vision, loss of consciousness, and reduced brain function [29]. It is emitted from incomplete combustion of biomass fuel, vehicles, industries, tobacco smoking, and other forms of biomass burning. According to Kurt et al. (2016) and Lelieveld et al. (2015), CO and $PM_{2.5}$ are the cause of more than 3.1 million deaths per year globally [24, 30]. Table 2 compares the 2005 and most recent 2021 WHO annual guideline levels for $PM_{2.5}$ and CO [31, 32].

Table 2: World Health Organization Air Quality Guidelines

Pollutant		2005 Air quality guidelines	2021 Air quality guidelines
$PM_{2.5}$	Annual	10 μg/m^3	5 μg/m^3
	24-hour	25 μg/m^3	15 μg/m^3
CO	24-hour	7 μg/m^3 (6.11 ppm)	4 μg/m^3 (3.49 ppm)
	8-hour		10 μg/m^3 (8.73 ppm)
	1-hour		35 μg/m^3 (30.55 ppm)
	15min		100 μg/m^3 (87.29 ppm)

Source: WHO, 2021[31, 32]

1.2. Household air pollution

Household air pollution (HAP) is caused largely by the use of fuel inefficiently and incomplete combustion of fuels in and around the home. It is a public health challenge globally and a risk factor for mortality and morbidity [26]. There are over fifty sources of HAP, and these sources vary by country and region, including building construction materials, mosquito repellents and pesticides, cleaning chemicals, indoor tobacco smoking, and biomass fuels for cooking [33]. Individuals from low socio-economic strata in low- and middle-income countries can be exposed to very high levels of indoor air pollution, particularly in ill-ventilated homes [33]. Individuals from low socio economic strata are also much more likely to use biomass fuels for cooking and heating compared to cleaner sources such as Liquified Petroleum Gas (LPG) and electricity [34]. Of the sources of HAP, the use of biomass fuels for cooking and heating is one of the leading risk factors for death and disability in developing countries [35]. Nearly half of the world's population uses biomass fuels in firewood and charcoal as their primary energy source [36]. The incomplete combustion of these biomass fuels emits substances such as CO, $PM_{2.5}$, NO_2, SO_2 and other substances related to HAP that in combination are estimated to cause 27% of pneumonia, 18% of stroke, 20% of COPD, 27% of ischemic heart disease, and 8% of lung cancer globally [37].

Of other sources, $PM_{2.5}$ can also be emitted due to efforts to curb the burden from vector-related diseases, mosquito chemical repellents and coils used particularly in Sub-Saharan Africa. These repellents leave harmful residues in homes when sprayed over prolonged period for months [38] and $PM_{2.5}$ is emitted when mosquito coils are burnt. This concentration is comparable to burning 100 cigarettes [33, 39]. Cleaning chemicals have also been found to emit volatile compounds that contribute to HAP [40]. Indoor tobacco smoking is also a major source of HAP that affects smokers, occupants residing with or in close proximity to the smoker (second-hand smoke) and visitors to the smoker's home or surroundings [33].

Studies have found CO and $PM_{2.5}$ to be important constituents of HAP, and respiratory and lung function studies from developing countries have shown an association between biomass fuel use and prevalence of respiratory symptoms and diminished lung function [41, 42]. For example, Kurmi et al. (2014) found CO concentrations at 24-hour mean were above threshold limits in Nepalese populations with biomass fuel use [43], while Guo et al. (2018) showed that every 5 $\mu g/m^3$ increase in $PM_{2.5}$ in the Taiwanese population was associated with a 1.46% reduction in Forced Expiratory Volume (FEV_1) and 1.18% in Forced Vital Capacity (FVC) [44]. Exposure to biomass leads to a decrement in lung function, particularly in women who use biomass for cooking and are likely to have greater exposures than men [45]. Gender inequality in sub-Saharan Africa has led to more women, their newborns and children than men being exposed to HAP because they spend a substantial amount of time performing kitchen duties [11]. The inhalation of PM by newborns and children is one of the leading causes of pneumonia-related deaths in children under the age of five years [37]. Children exposed to HAP from early childhood are also predisposed to developing negative health outcomes later in life because of effects on their nervous, cardiovascular, endocrine and respiratory systems, with the respiratory system bearing the most effect [33].

High blood pressure has also been found to be influenced by biomass exposure and to be a risk factor for development of cardiovascular disease and hypertension [46, 47]. Many studies have investigated the relationship between $PM_{2.5}$ and elevated blood pressure based on both ambient and personal exposures [48]. Short-term exposure to $PM_{2.5}$ has been linked to altered systolic and diastolic blood pressure and pulse pressure, however most of these studies were conducted in high- and middle-income countries with relatively low $PM_{2.5}$ concentrations [47]. Young et al. (2019) found HAP from biomass fuel to be associated with high systolic and diastolic blood pressure in Honduran women [49], while Huang et al. (2018) demonstrated in individuals living in Michigan and Beijing that short-term exposure to $PM_{2.5}$ can affect blood pressure even in healthy adults in environments with concentrations above normal respirable limits [50].

1.3. Occupational air pollution exposure

Occupational diseases are an important contributor to the global burden of disease. According to the WHO and International Labour Organization (ILO), occupational- related diseases and injuries led to an estimated 1.9 million deaths in 2016, with 81% linked to non-communicable diseases (mostly COPD, stroke and ischaemic heart disease) and the remaining 19% due linked to injuries [51]. Occupational exposure to air pollution in the form of dusts, fumes, vapors, and toxic gases caused 450,000 deaths [51].

Many studies of occupational workers in industries such as coal or gold mining, asphalt production, textile, industries, commercial motorcyclists/taxi drivers, and hairdressers have concluded these workers are exposed to high levels of air pollutants and that this exposure leads to detrimental health effects [52-55]. For example, Obiebi et al. (2019) found coal mine workers in Nigeria had an increased prevalence of respiratory symptoms (the most common being cough and shortness of breath) and reduced lung function (forced expiratory volume, FEV_1, and forced vital capacity, FVC) due to coal dust exposure [56]. Similar findings were reported by Nagoda et al. (2012) with textile spinning and weaving workers in Nigeria for respiratory symptoms including cough and phlegm [52]. Adefuye et al. (2015) found that motorcyclists in Nigeria frequently sneezed, had cough and chest-tightness presenting with more restrictive lung patterns than obstructive defect or mixed patterns [53]. Ghosh et al. (2014) found dust exposure at a rice mill work site in India to be associated with increased respiratory symptoms and adverse lung function parameters among workers [57]. These studies demonstrate increased prevalence of respiratory symptoms but indicate differences in observed occurrence of symptoms based on the specific occupation. Many of these occupations involve the use of 'traditional' cookstoves that burn solid fuels. In sub-Saharan Africa, studies have shown that such cookstoves lead to ailments such as COPD, acute lower respiratory infections (ALRI) and decreased lung function [58, 59].

2. Air pollution in the African context

In Africa, over recent years, there have been increasing levels of urban air pollution and relatively little surveillance on air quality. Of the few assessments of exposure in the African context, urban air pollution has been observed in the Saharan dust (Harmattan) around mid-November to late March, and in dry seasons in the Economic Community of West African (ECOWAS) nations [63]. The ECOWAS nations have experienced an increase in air pollution owing to population increase, urbanization, increases in motor transports, and industrialization [63]. These nations are also prone to receiving Saharan dusts (Harmattan) due to their proximity to the Sahara Desert. Recent findings on HAP studies in the African region indicate the burden of disease from indoor HAP is on the decline, whereas the burden associated with ambient air pollution is increasing [12, 64]. The downward trend is as result of households making the switch in recent years from wood to either liquified petroleum gas or charcoal burners [65]. These findings on the decline of the burden of disease from HAP are thanks to prolonged interventions by organisations at both the government and non-governmental level [64]. There is evidence that this exposure makes populations, particularly women, children, older people, and individuals with predisposed conditions vulnerable to diseases associated with air pollution [11]. There are also indirect impacts of biomass fuel use on the health of women and young girls due to indirect effects of biomass when sourcing these fuels. They travel long distance to gather these fuels and usually carry them on their heads resulting in musculoskeletal injuries [66]. Moreover, time spent gathering wood leads to loss of access to education and opportunities for work [67].

2.1 Air pollution in Ghana

Ghana, formerly known as the Gold Coast, is located in West Africa. It borders Burkina Faso to the north, Ivory Coast to its west, and Togo to its east. Ghana's land mass area is 238,535 km^2 along the Atlantic coastline, covering biomes from coastal savannas to tropical rain forests. Ghana has a tropical wet season and humid dry season climate. It has the second largest population in West Africa, with more than 31 million people, behind only Nigeria. About 29% of the population are children and adolescents under the age of 15, while over 50% of its population are above the age of 15 and under the age of 65. The average life expectancy in 2020 was 65 years for the males and 71 years for females. Ghana is 71.3% Christian, 19.9% Muslim faith communities, and 3% engage in traditional practices, and the main ethnic group is the Akan [68].

In Ghana, biomass fuel accounts to over 65% of household use and exposure to HAP leads to an estimated loss of 450,000 DALYs annually [69]. About 75% of households in Ghana rely on biomass fuel for cooking and 94% of these are households in rural communities who use firewood and/or charcoal [70]. Access to clean cooking energy is dependent on socio-economic strata and the International Energy Agency (IEA) reports that only about 25% of households in Ghana have access to clean cooking energy [71]. Thus, there is heavy reliance on biomass fuels that is also leading to massive deforestation in Ghana [72]. The Institute for Health Metrics and Evaluation (IHME) reported that lower respiratory infections were the fifth leading cause of Disability-Adjusted Life Years (DALYs) in Ghana after malaria, neonatal disorders, stroke and HIV/AIDS, as shown in Figure 4 [73].

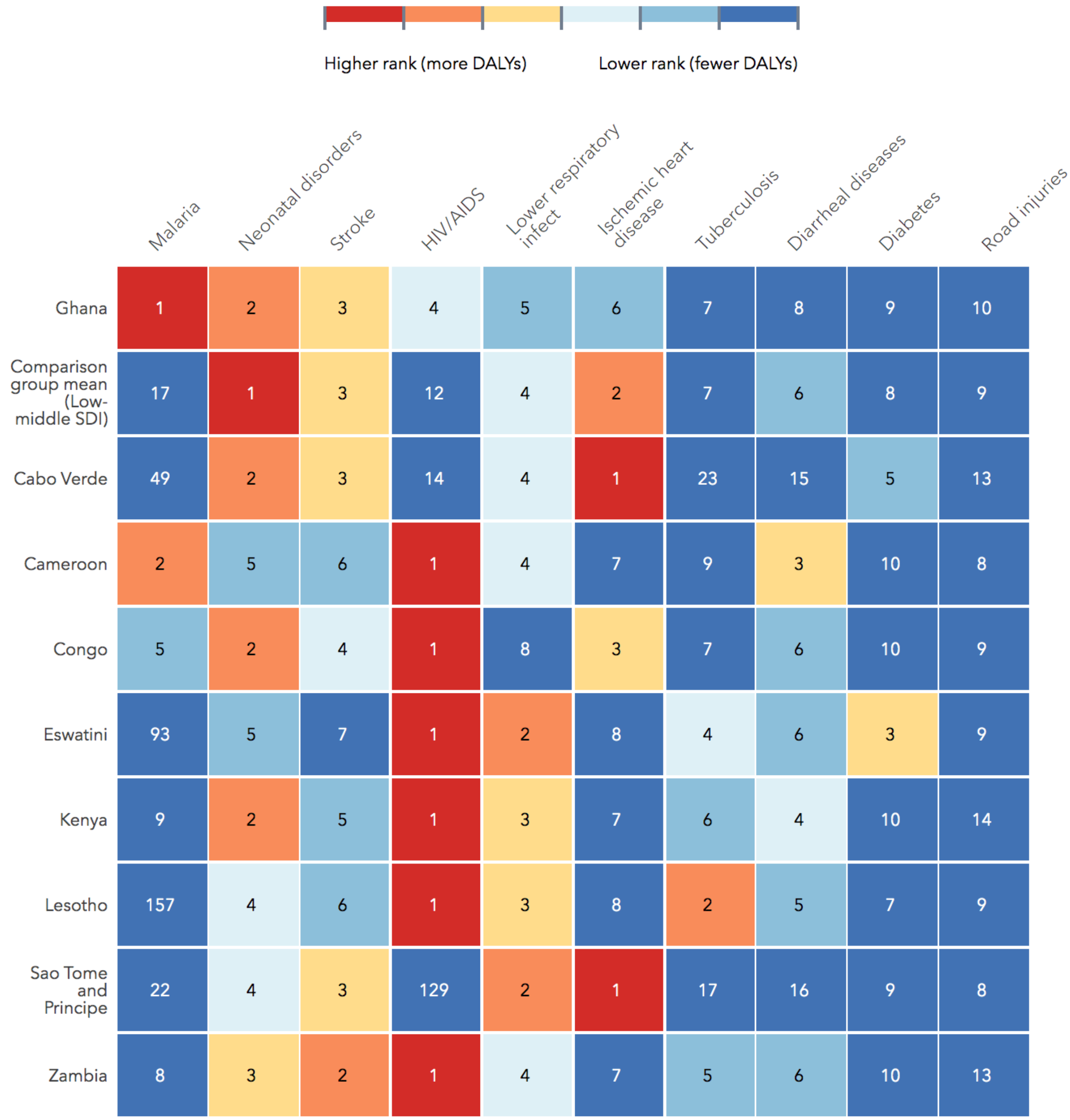


Figure 4: Estimated DALY per 100 000 compared to other locations, 2019 **Source:** IHME [73]

2.2. Air pollution in food processing settings in sub-Saharan Africa

In sub-Saharan Africa, various food processing industries make use of non-clean cooking energy in the form of biomass fuels. These activities include, but are not limited to, fish smoking, meat or kebab grilling, dough frying, plantain grilling, and coffee processing. Pollutants emitted by these activities have been reported to affect the respiratory system, lead to ocular defects, cardiovascular problems, and other non-respiratory diseases [74-76]. Adewole et al. (2013) and Dienye et al. (2016) found exposure to biomass smoke and oil fumes and duration on the job from fish smoking, meat or kebab grilling in Nigeria to be responsible for an increased prevalence of respiratory symptoms and abnormal pulmonary function [75, 76]. Findings in Awopeju et al. (2017) found significantly higher respiratory symptoms and airway obstruction in street cooks exposed to biomass smoke in Nigeria compared to a control group not occupationally exposed [77]. Besides biomass occupationally-exposed workers, Abaya et al. (2018) and Bråtveit et al. (2021) found chronic respiratory symptoms and diminished lung function in coffee processing workers exposed to high dust levels in Tanzania and Ethiopia [78, 79].

2.2.1. Cassava grits processing industry in Ghana

One important economic activity that involves biomass burning and has the potential for high levels of biomass-related air pollution exposure is cassava grits processing. Cassava grits, popularly known as 'Gari', is a staple food that is rich in carbohydrate and made from fermented cassava. Cassava, also referred to as manioc (Manihot esculenta Crantz), is an agri-food crop that provides food security for households in many parts of Africa [80]. Ghana is the third largest producer of cassava in sub-Saharan Africa and fourth in the world [81] (Table 3).

Table 3: Top nine Producing Cassava Nations in the World

	Country	Production %	2013	2014	2015	2016	2017	2018	2019
1	Global		278.42M	288.20M	291.08M	290.65M	286.7M	295.05M	303.57M
2	Nigeria	19.5%	47.41M	56.33M	57.64M	59.57M	55.07M	55.80M	59.19M
3	Democratic Republic of Congo	13.19%	33.92M	34.87M	34.93M	35.00M	37.70M	38.87M	40.05M
4	Thailand	10.24%	30.23M	30.02M	32.36M	31.16M	30.50M	29.37M	31.08M
5	Ghana	7.39%	15.99M	17.80M	17.21M	17.80M	19.01M	20.85M	22.45M
6	Brazil	5.76%	21.48M	23.25M	23.06M	21.04M	18.50M	17.88M	17.50M
7	Indonesia	4.81%	23.94M	23.44M	21.80M	20.26M	19.05M	16.12M	14.59M
8	Cambodia	4.53%	7.55M	8.41M	10.12M	10.94M	11.87M	12.81M	13.74M
9	Vietnam	2.33%	9.76M	10.21M	10.74M	10.91M	10.27M	9.85M	10.11M
10	Angola	2.96%	16.41M	7.64M	7.73M	7.92M	8.33	8.73M	9.00M

Source: 2019 data from TRIDGE [81]

According to the Ghana Export Promotion Authority (GEPA) of the Ministry of Trade and Industry, over 22 million metric tonnes of cassava was produced in 2019 in Ghana. However, only about 15 million was available for human consumption [82, 83], of which a large percentage was consumed in processed products such as 'gari' and 'kokonte' [82]. A summary of cassava production in Ghana between 2016 and 2019 is provided in Appendix A.

Table 4: Per Capita Consumption of food crops by category

	Commodity	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
1	**Starchy Staples**						
	Cassava	148.00	149.70	151.40	152.90	152.90	152.90
	Yam	43.30	42.80	42.30	41.90	125.00	125.00
	Cocoyam	54.00	55.00	56.00	40.00	40.00	40.00
	Plantain	83.00	83.50	84.00	84.80	84.80	84.80
2	**Cereals**						
	Maize	40.30	41.40	42.50	43.80	45.00	45.00
	Rice (milled)	13.30	13.90	14.50	15.10	32.00	32.00
	Millet	5.10	12.60	9.00	6.40	5.00	5.00
	Sorghum	9.30	21.70	14.80	10.10	5.00	5.00
	Wheat	-	-	8.00	8.00	13.00	13.00
3	**Legumes**						
	Cowpea	4.00	4.00	4.00	5.00	5.00	5.00
	Groundnut	20.00	20.00	20.00	12.00	12.00	12.00
	Soya bean	-	-	-	-	2.00	2.00
4	**Fish**	23.60	24.20	27.00	30.20	24.50	24.50
5	****Meat**	8.00	6.30	6.70	9.40	12.00	11.00

*In the absence of a household consumption survey, these estimates have been based on food available for human consumption (i.e., apparent consumption) from both domestic and import sources.

**For Meat; total meat available for consumption comprising, domestic meat production (incl. meat from the wild [bush meat] averaging 92,000 Mt per annum) plus meat imports have been considered. Dashes indicate cells for which formation was not available.

Source: Estimated Levels of Apparent Per Capita Consumption of Selected Commodities (5yr. interval). Statistics, Research and Information Directorate, Ministry of Food and Agriculture [83]

The Ministry of Food and Agriculture in Ghana identifies cassava as one of the most produced food crops in the country [82, 83]. Table 4 summarizes consumption of food crops by category over the past decade. Since the 1990's, cassava has been the most consumed food crop per capita. The gari processing industry is mostly situated in the Bono East region in the centre of the country. Figure 5 highlights two districts in the Bono East region that are the centre for gari processing the country: Kintampo South District and Techiman North District.

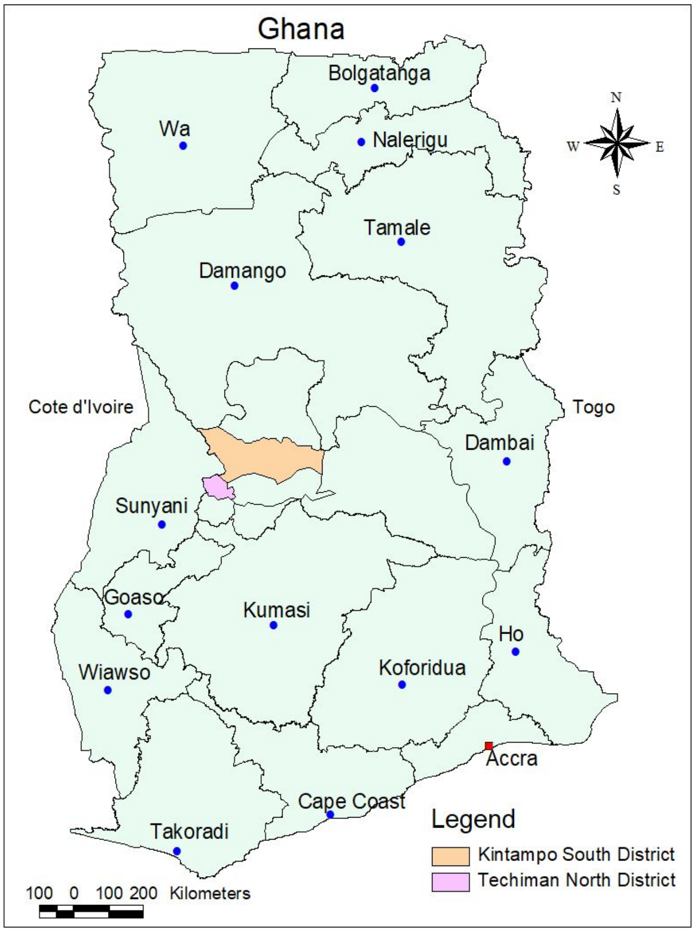


Figure 5: Map of Ghana highlighting gari processing districts

Before cassava is processed into gari, it goes through a five-stage process after cleaning. First, it is peeled either manually by labourers or with a machine and washed thoroughly. Second, it is grated and ground into grits-like products in a machine. Third, the grated grits are put in large sacks to ferment and press (de-water) for a few days. De-watering involves the use of hydraulic jacks or a bolt screw to compress the sacks containing the grated fermented cassava for 24-30 hours [58]. Fourth, the de-watered and dried grits are sieved to remove large unbroken cassava quantities. Fifth, the sieved grits are transferred to a large open biomass frying pan to process into the final product into gari [80]. The fried grits are cooled, poured into appropriate sealable sacks or plastic lining, and bagged for trade or stored. These labour-intensive processing stages are portrayed in Figure 6. The means of processing gari can also be carried out with automated machineries as shown in Figure 7.

Figure 6: Stages of Gari processing in Bono East region **Source:** Cassava - Britannica [84]; Grating/grinding – IITA [85]

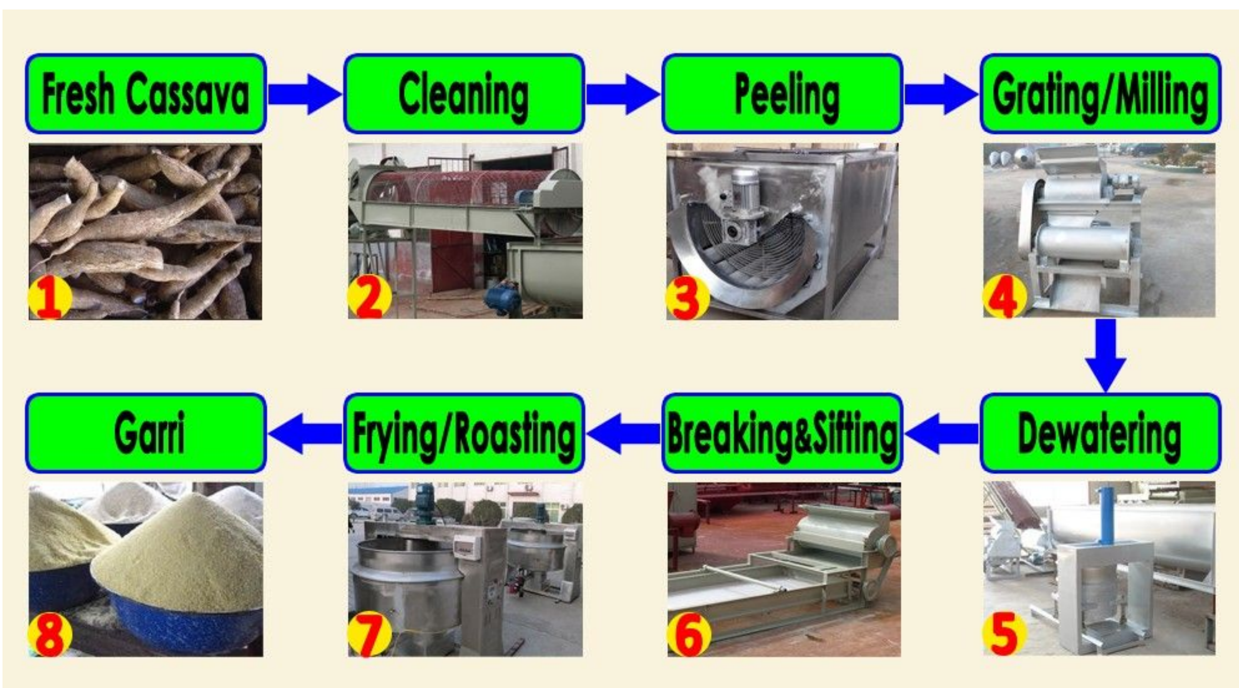


Figure 7: Stages of Gari processing in ideal setting **Source:** DOING, 2019 [86]

Workers at the fifth stage of gari processing (grits fryers) are likely to be exposed to high levels of $PM_{2.5}$ and CO from the biomass cookstoves [58]. These workers (grits fryers performing cookstove activity), who are mostly women, stand for long hours (up to 8 hours each day) by the traditional cookstoves in open area sheds for six to seven days per week [87]. Grits fryers also take their children along with them to the gari processing site [88]. The biomass fumes have also been known to contribute to environmental pollution in communities located near industrial processing sites [80, 89].

Women standing and sitting by biomass stoves processing gari.

Children are in the center of a gari processing site, most likely for 6-10 hours a day as their mothers/caregivers are being exposed to biomass smoke.


A gari worker using a small foam cushion to lean on the side of a hot biomass stove to process the gari.

A gari worker prepares to start the gari frying process.

One of the few male workers seen processing gari at one of the sites.

Biomass stove with large logs of burning firewood.

Figure 8: Photos of workers and their children being exposed to pollutants at the gari processing sites

Few studies in Ghana have focused on the occupational and environmental hazards posed by the gari processing industries, and there has been limited assessment on the nature and effects of biomass exposure in this setting [89, 90]. These include environmental hazards from biomass burning, cassava peels and effluents that lead to air pollution and insect infestation due to improper waste disposal. In Ghana, manual processing of gari is largely the norm. This requires manual effort being performed at all stages of processing and leads to occupational hazards such as biological, chemical, ergonomic, musculoskeletal disorders, physical. This labour-intensive method includes strain and pain, especially ergonomic risks causing reduced productivity and discomfort in workers [89]. However, few papers exist that address some of these hazards in Ghana. For instance, at the cassava peeling stage workers experience knife cuts, itching from cyanide present in cassava, arm and shoulder pain, lower back pain from prolonged sitting. At the grating and grounding stage, workers slip and fall from the watery ground surface, and injuries from using their hands to push the cassava down the grater to enable faster grating. At the de-watering stage, similar to the previous stage, slips and falls occur and pains around parts of the lower and upper body joints because it involves a lot of bending and carrying of the sacks with the fermented grated grits [89, 91, 92]. At the frying stage, the air pollution from the incomplete combustion of biomass may be posing pathological damages to the respiratory system in the body but inadequate information exists on the lung function abnormalities.

2.2.2 Knowledge gap and thesis justification

Most research on air pollution in developing countries has to date focused on HAP rather than occupational exposure. For example, the Ghana Randomized Air Pollution and Health Study (GRAPHS) was conducted in Ghana, aiding the implementation of the current clean cookstoves in Ghana [59-62]. These HAP studies have helped reduce the use of biomass and helped with promotion of liquified petroleum gas for cooking in household settings. However, limited evidence exists on the health effects of biomass exposure from occupational air pollution.

From the existing literature, there are limited identifiable published studies that have been conducted in Ghana on air pollution exposure among grits fryers in the gari processing industry and its relationship to respiratory symptoms and lung function abnormalities (see Table 6 of Chapter 2). The few studies published on biomass exposure from this industry are mostly from Nigeria, West Africa, and these studies generally used aerial monitoring of pollutants rather than more accurate personal exposure monitoring and have not explored extensively the association between $PM_{2.5}$ and/or CO and respiratory health [87, 89, 93]. This thesis will attempt to fill this gap in knowledge at the frying stage of gari processing. The need for evidence is especially acute because of the high prevalence of women in the gari industry in Ghana. Moreover, Ghana is transitioning to cleaner fuels including those used in occupational settings, so evidence is needed about workers in the gari industry to plan for their transition.

3. Thesis structure

This Doctor of Public Health (DrPH) thesis is in 'book style', following the traditional thesis format. The thesis provides a systematic account of my research on occupational air pollution and lung function among cassava grits processors in the Bono East region of Ghana. After Chapter 1 introducing the relevant background on air pollution and health at the household and occupational levels, Chapter 2 presents the aim, objectives, and research questions. Chapter 3 contains information on the methodology used for the research. It presents the study population and setting, eligibility criteria and enrolment of study participants, data collection narrating the breakdown of study activities. Chapter 4 contains an overview of the results of the study. Chapter 5 presents a discussion based on the findings of the thesis, including the implications of the work, its strengths and limitations, recommendations, and potential areas for future research. Chapter 6 presents the conclusions of the thesis.

3.1. Role of the candidate

This DrPH thesis assessed exposure to air pollution and lung function in an occupational group and compared this against an unexposed group because of the complex public health concerns for the occupational group. From November 2019 to December 2021, I was the principal investigator who performed the data collection described in the thesis. The work builds on my internal and external supervisors' extensive experiences with air pollution on the global stage. Based on their feedback and advice, I developed and drafted the research protocol. I performed the statistical data analysis, interpreted the data, and wrote up the results with input from my supervisors.

3.2. Timeline

I commenced preparation for the thesis in February 2019. Planning and preparation for the study took one year and ten months due to delays caused by the logistics of research devices and the coronavirus pandemic. Data collection began in February 2021 to June 2021. The Gantt chart in Table 5 indicates the timeline for the planning and preparation process before data collection, data analysis and write-up.

Table 5: Gantt chart for thesis timeline

Task	Start	Finish
Preparatory work		
Meeting with supervisors	Cont'	n/a
RSII protocol development	24-Feb	31-May
Meeting with advisory committee	Cont'	n/a
DrPH review	19-Jul	19-Jul
Scientific Review and Ethics approval	20-Jul	19-Nov
Study tools (calibration and training)	20-Nov	15-Dec
Meeting with advisory committee	12-Dec	12-Dec
Study device change	05-Jan	22-Mar
Lockdown		
Study disruption - Pandemic lockdownn	23-Mar	13-Nov
Systematic review	10-May	n/a
Exposed and unexposed study		
Prepare study tools	01-Dec	29-Jan
Meeting with advisory committee	12-Jan	12-Jan
Pilot study tools	01-Feb	19-Feb
Data collection	24-Feb	09-Jun
Data cleaning	05-Jul	31-Jan
Data analysis	27-Sep	14-Sep
Writing-up		
Prepare first draft of thesis report	15-Sep	20-Apr
Prepare second draft of thesis report	21-Apr	30-Jul
Finish thesis draft	31-Jul	31-Oct
Revise thesis report	01-Nov	29-Nov
Prepare to submit thesis report	30-Nov	04-Dec

CHAPTER 2: AIM AND OBJECTIVES

2.1. Problem statement

Cassava is one of the most produced food crops in Ghana, with more than 22.6 million metric tons produced yearly [94]. The Bono East region of Ghana is commonly known for gari processing, employing more than 10% of its population combined from both the Kintampo South and Techiman North districts [95, 96]. The steps involved in gari processing result in several potential occupational hazards to both the environment and persons employed in the industry. To the environment, these hazards include local air pollution emissions from incomplete combustion of biomass, water pollution from improper water disposal during the de-watering process, deforestation and desertification owing to the use of firewood for the large metal biomass cookstoves in frying the sieved grits [80, 97]. To the persons involved directly and indirectly in gari processing, a key hazard is inhalation of smoke from the incomplete combustion of biomass and cyanide from byproducts of cassava peels [89]. Gari processing poses additional occupational hazards such as eye, nose and throat irritation from prolonged smoke exposure, skin irritations from contact with the cassava peels, heat stress, musculoskeletal injuries from carrying firewood on their heads and from prolonged sitting or standing at the various processing stages [89, 98, 99]. Women and children are likely to be most susceptible to these occupational hazards. From what is known on the effects of household air pollution affecting birth outcomes, child health, morbidity and mortality rates, there is a need to introduce appropriate interventions such as efficient clean cooking energy to reduce possible impairments due to industrial air pollution [87].

Rationale

The number of people affected by occupational-related diseases and injuries globally, including in Africa, is estimated to be about 2.78 million deaths, representing a considerable global_public health burden [100]. The United Nations Global Compact emphasized the occupational safety and health as a sustainable development priority under Goal 8 in 2022 and issued a call to action to address challenges posed to vulnerable groups (women and children) [100]. Improving occupational health and safety has become an increasingly important policy objective in Ghana in recent years, though these objectives have not been translated into implemented action in many cases._As a Member State of the ILO, Ghana is expected to promote a safe and healthy working environment, regardless of relevant Conventions being ratified by the nation. However, fundamental Conventions and Protocols have largely been documented by the nation but not implemented under formal obligation as a national priority [101]. In July 2023, the Government of Ghana, the ILO, and various ILO stakeholders created a Programmed called ‘Decent Work Country Programme III’. The priority of this programme is intended to encompass improving working conditions and working environments to ensure workers safety and health under the ILO standards. However, in a report released by the Ghana Ministry of Employment and Labour Relations, “these priority areas were designed to help

Ghana achieve its national development goals, such as creating employment opportunities for all Ghanaians and building a thriving nation" [102].

Despite the known health risks of air pollution,_relatively little is known about occupational exposure to biomass fuel and its health effects, especially in countries such as Ghana. Air pollution studies in sub-Saharan Africa have focused heavily on the household level rather than on biomass occupational industries [103]. Limited evidence exists for biomass smoke exposure in occupational settings such as the gari processing industry. The association between biomass smoke exposure and health effects on workers has been explored more in other food processing industries including fish smokers, bean cake, and grilled meat [75, 76].

This research focuses on the cassava processing (Gari) industry that is an important source of livelihood for many rural women in Ghana and involves prolonged exposure to biomass smoke. The thesis will report exposures to air pollutants that are partly produced by biomass fuel burning in this industry and respiratory health conditions among workers in compared to a comparison group from the same community. To the best of my knowledge, there is no research to date about Gari processing personal exposure to biomass smoke and its health impacts in Ghana. Based on a rapid scoping review of the academic literature, I identified six previous similar studies. The studies are summarised briefly in Table 6 to demonstrate their relative strengths and limitations. The literature search included search terms on air pollution, particulate matter, carbon monoxide, exposure, biomass, environment, occupational, respiratory infection, Africa, and health. Target databases were PubMed, Medical Literature Analysis and Retrieval System Online (MEDLINE), Excerpta Medica database (EMBASE), and the London School of Hygiene and Tropical Medicine (LSHTM) Library, Archive and Open Research resources.

Information on the occupational studies identified through the search is shown in Table 6.

Table 6: Similar occupational studies

Study (General information)	Oloyede et al. (2018) [58]	Okwor et al. (2017) [87]	Dienye et al. (2016) [75]	Umoh et al. (2013) [104]	Adewole et al. (2013) [76]	Awopeju et al. (2017) [77]
Country of origin	Nigeria	Nigeria	Nigeria	Nigeria	Nigeria	Nigeria
Study design	Cross-sectional	Cross-sectional	Case control	Cross-sectional	Case control	Cross-sectional
Population characteristics						
Source of population	Cassava grits processors	Cassava grits processors	Fish smokers (Fishing settlement)	Fishermen (fish smokers)	Mai Suya (meat grillers)	Street cooks
Inclusion criteria	- Workers active in gari processing for at least a year	- Workers active in gari processing for at least a year	- Workers active in fish smoking for at least a year - Controls residing in Oyorokoto fishing settlement and having not dwelt in same houses as fish smokers	- Fishermen exposed to firewood smoke - Controls were fishermen residing in same fishing settlements	- Workers active in Mai Suya (meat grilling)	- Active as street cooks for at least 6 months - Controls who only cooked at home - Controls on same street as street cooks
Exclusion criteria	Pre-existing diseases such as asthma, heart diseases, chronic obstructive pulmonary disease or smoking	- Pre-existing asthma, pulmonary tuberculosis, obvious skeletal chest abnormalities - Pregnant individuals - Previous history of work in a dusty environment - Smokers - Controls excluded with previous history of occupational biomass exposure	- Pre-existing asthma - Males - Smokers - Workers excluded with previous history of occupational biomass exposure - Workers excluded with previous history of work in a dusty environment or having lived in the same houses as fish smokers - Workers excluded with previous history of work in a dusty environment - Controls excluded if having lived in the same houses as fish smokers	None stated	- Pre-existing asthma or tuberculosis - Controls excluded with previous history of occupational biomass exposure	- Controls excluded with previous history of occupational biomass exposure
Total number of participants recruited in the intervention group	351 cassava processors	264 cassava processors	181 fish smokers	521 fishermen exposed	48 Mai Suya (meat grillers)	188 street cooks
Total number of participants recruited in the Control group	351 from residential areas (no occupation stated)	264 petty traders	181 non-fish smokers	545 non-fish smokers	32 from residential areas (no occupation stated)	197 controls (combination of petty traders, seamstresses and hair beauticians)
Characteristics of study group (worker group and control group)	**Worker group:** - Between 15-59 years	**Worker and Control:** - Between 13-60 years	**Worker and Control:** - Between 15-64 years	**Worker group:** - Between 20-60 years	**Worker and Control:**	**Worker and Control:** - Between 20-75 years

- Age - Sex - Socio-economic status	- 318 Females and 33 Males - Low social strata **Control group:** - Same age group and social strata - 316 Females and 35 Males	- Females only - Low social strata	- Females only - Low social strata	- 342 Females and 179 Males - Low social strata **Control group:** - Same age group and social strata - 350 Females and 195 Males	- Mean (SD): 30.33 (6.7) for worker group versus 29.17 (9.7) for control group - Males only - Low social strata	- Females only - Low social strata
Assessments						
Health	Respiratory health and ventilatory function	Respiratory health and ventilatory function	Respiratory health and ventilatory function	Respiratory health and ventilatory function	Respiratory health and ventilatory function	Respiratory health and ventilatory function
Exposures	Biomass exposure (unidentified pollutant)	$PM_{2.5}$ and PM_{10}	Biomass exposure (unidentified pollutant)	Biomass exposure (unidentified pollutant)	Biomass exposure (unidentified pollutant)	Volatile organic compounds
objective assessed in the study	FEV_1, FVC, FEV_1/FVC	FEV_1, FVC, FEV_1/FVC	PEFR	FEV_1, FVC, FEV_1/FVC	FEV_1, FVC, FEV_1/FVC, PEF	FEV_1, FVC, FEV_1/FVC
Spirometer assessment	Yes	Yes	Yes	Yes	Yes	Yes
Self-reported symptoms (Questionnaire based)	Yes	Yes	Yes	Yes	Yes	Yes
Self-reported exposure	None	None	None	None	None	Yes
Aerial exposure monitoring >24 hours	None	None	None	None	None	None
Aerial exposure monitoring <24 hours	None	Yes, but between 10AM and 3:30PM for two days	None	None	None	None
Personal exposure sampling > 24 hours	None	None	None	None	None	None
Personal exposure monitoring <24 hours	None	None	None	None	None	None
Confounding factors	- Passive cigarette smoking - Vehicular smoke - Domestic (biomass burning in community	None stated	- Age, height and weight	- History of cigarette smoking	- History of cigarette smoking - Dust and fumes from vehicle exhaust	- Domestic exposure to biomass smoke - Traffic pollution - History of cigarette smoking
Results						
Primary outcome	- Higher prevalence of respiratory symptoms observed in worker group compared with the control group - Lower pulmonary function parameters in worker group	- Higher prevalence of respiratory symptoms observed in worker group compared with the control group - Lower pulmonary function parameters in worker group	- Higher prevalence of respiratory symptoms observed in worker group compared with the control group - Lower pulmonary function parameter in worker group	- Higher prevalence of respiratory symptoms and chronic bronchitis observed in worker group compared with the control group - Higher frequency of workers with chronic bronchitis had obstructive defect than restrictive pattern	- Higher prevalence of respiratory symptoms observed in worker group compared with the control group - Lower pulmonary function parameter in worker group irrespective of smoking status	- Higher prevalence of respiratory symptoms observed in street cooks compared with the control group - Higher frequency of airway obstruction in street cooks

	- 162 (46.2%) in the worker group had ventilatory function abnormalities. Of these, 26.2% for restrictive pattern, 17.7% for obstructive and 2.3% for mixed pattern	- Higher frequency of obstructive defect than restrictive pattern in worker group - High levels of $PM_{2.5}$ concentration in worker group		- Lower pulmonary function parameter in worker group		
Extra useful information						
Limitations stated	None stated	Self-reported data	- No assessment of dose-response for possible effects of chronic exposure - No causal sequence interpretation - No reference value of lung function parameter in study vicinity - One pulmonary function parameter measured	None stated	- Self-reported data - Portable office spirometer	- Self-reported data - No assessment of dose-response for possible effects of chronic exposure - Only measured volatile organic compounds in subsample of population

None of the identified studies were performed in Ghana, with all being conducted in Nigeria and the majority were based on surveys, focus group discussions, or interviews leading to self-reported assessments. None of the studies included detailed monitoring of exposure to air pollutants, though one did perform a crude exposure assessment study based on aerial monitoring. For example, Fosu-Mensah et al. (2021) and Adenugba and John (2014) assessed working conditions in the gari processing industry and found workers had increased prevalence of respiratory symptoms and musculoskeletal disorders with duration of work [89, 99]. Adewole et al. (2013) and Dienye et al. (2016) found exposure to cook smoke in kebab and fish smokers to be associated with increased risk of respiratory symptoms and reduced pulmonary function [75, 76].

Oloyede et al. (2018) performed a cross-sectional study using spirometry to measure pulmonary indicators and assess ventilatory function. They found 46.2% of gari workers had abnormal ventilatory function parameters compared to 6.8% in comparisons. Both FVC and FEV_1 were significantly lower in gari workers than comparisons [58]. All the occupational studies shown in Table 6 conclude that workers are at an increased risk of developing respiratory symptoms and reduced lung function with prolonged biomass exposure [74, 76, 87-89]._The review demonstrates the paucity of work in the gari processing industry on personal exposure to air pollution and its relationship with respiratory symptoms and lung function in Ghana. As such, this thesis uses personal monitoring to improve the exposure measurements and individually-linked associations between exposure and pulmonary function and respiratory symptoms.

2.2. Aim & Objectives

The aim of this research is to assess $PM_{2.5}$ and CO exposure among cassava grit processors and investigate their association with lung function measurements and respiratory symptoms in two districts in the Bono East region of Ghana.

Specific objectives were:

i) To characterize personal $PM_{2.5}$ and CO exposure of cassava grit processors and a comparison group
ii) To document respiratory symptoms among cassava grit processors and compare these to the comparison group using structured questionnaires
iii) To measure lung function among cassava grit processors and compare this to the comparison group

iv) To investigate the association between $PM_{2.5}$ and CO exposure, and lung function measurements among cassava grit processors and the comparison group.

The objectives are translated into a series of targeted research questions in Table 7:

Table 7. Objectives and research questions, Kintampo, (2021)

Objectives	Research Questions
i) To characterize personal $PM_{2.5}$ and CO exposure of cassava grit processors and the comparison group	A) In general, how much are the workers and the comparisons exposed to CO and $PM_{2.5}$ in the Bono East region of Ghana? B) How do CO and $PM_{2.5}$ exposure levels change during a day among the workers and the comparisons? C) Is cumulative exposure higher in the workers than the comparisons in terms of total and average exposure? D) What is the contribution of the occupational exposure to total exposure among the cassava grits processors?
ii) To document respiratory symptoms among cassava grit processors and compare to the comparison group using structured questionnaires	A) What is the health status of the workers and the comparisons in terms of respiratory symptoms and lung functions (baseline health status for each group)? B) Are there any differences in self-reported respiratory health status between the worker and the comparison group?
iii) To measure lung function among cassava grit processors and compare to the comparison group	A) Are there any differences in objective measures of pulmonary functions between the worker and the comparison group?
iv) To investigate the association between $PM_{2.5}$ and CO exposure, and lung function measurements among cassava grit processors and the comparison group	A) Is there an association between personal exposure to CO and $PM_{2.5}$ and lung function in the whole study population the Bono East region of Ghana? B) Are those associations different for the workers and the comparison group?

CHAPTER 3: METHODOLOGY

3.1. Study area

The study was conducted in the Bono East Region (area 22,952 km^2, population 649,727 in 2020), a newly formed region encompassed within the larger Brong-Ahafo region in central Ghana (Figure 9) [105]. The capital of the Bono East Region is Techiman. Bono East has two major climatic seasons; a wet season between June and November and a dry season between December and March [106, 107].

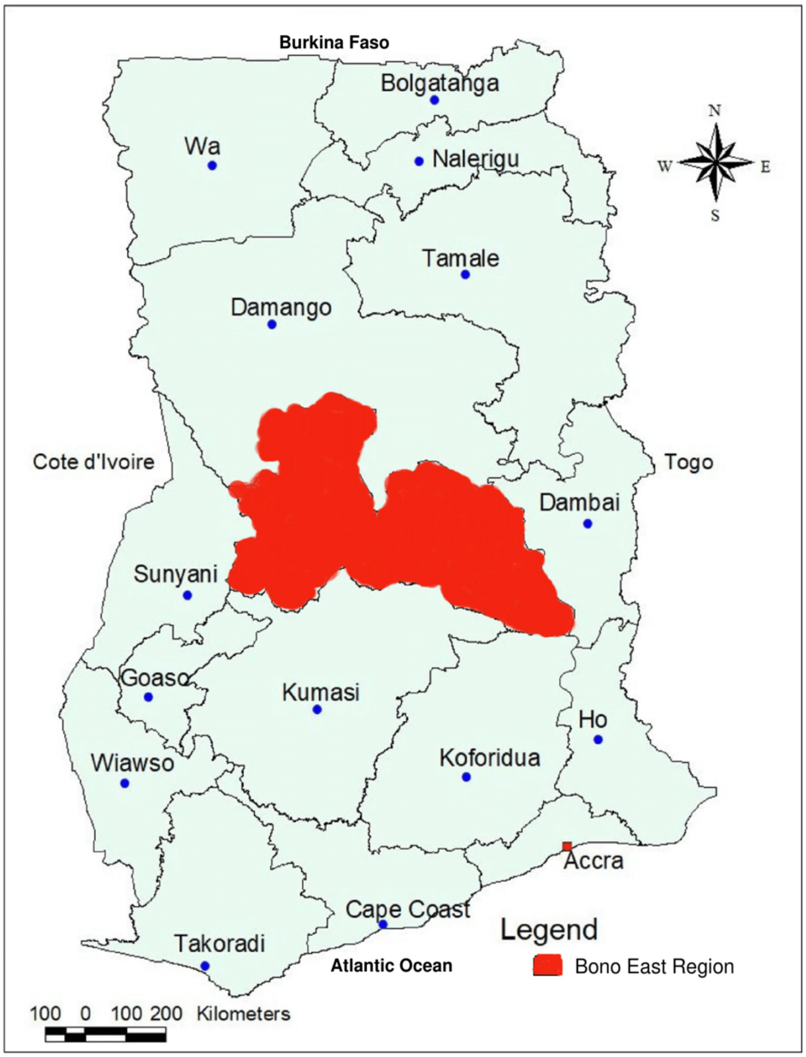


Figure 9: Map of Ghana highlighting Bono East region

Study participants were selected from two districts in the Bono East region: Kintampo South and Techiman North (total area 2,164km^2, population 92,213 in 2021, see Figure 9) [108]. The districts are part of the 260

Metropolitan, Municipal and District Assemblies in Ghana [96, 109]. These two districts were selected because a significant number of gari processing sites are situated there and a large number of cassava grits processors (i.e. workers performing cookstove activity on cassava processing sites) reside in the districts. In Kintampo South and Techiman North, biomass cookstoves with a large pan surface are used primarily to process the gari under an open shed area. The study sites comprised of two communities (Ntankro and Kwabia) in Kintampo South and six communities (Atrensu, Ayeasu, Aworowa, Akrofrom, Gyebiri and Krobo) in Techiman North (Figure 10).

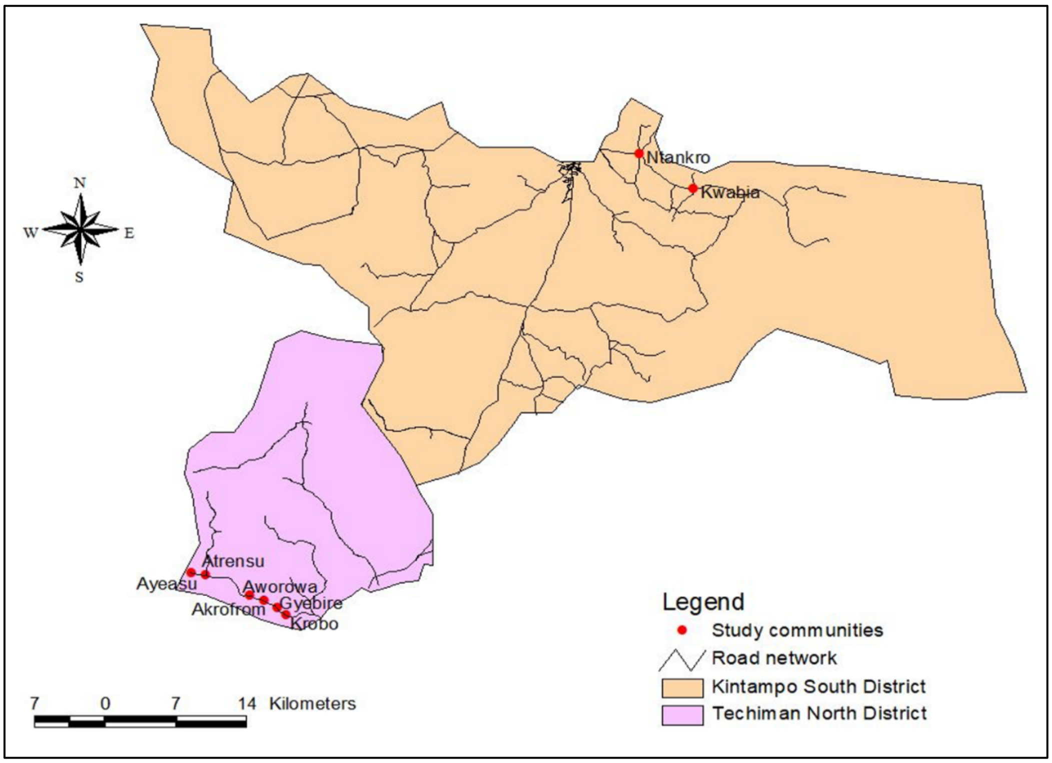


Figure 10: Study communities in Kintampo South and Techiman North districts

Agriculture is one of the main economic activities in the two districts, while the industrial sector comprises of small-scale industries such as cassava processing, metal works and charcoal processing, employing more than 10% of the population combined from both districts [95, 96]. Local sources of ambient air pollution include waste burning, tree burning, charcoal production, and food processing with biomass [110]. According to data from the Kintampo Health Demographic Surveillance System (KHDSS), most people attained only basic education at the primary level (Table 8).

Table 8: Summary of district characteristics

	Kintampo South District				Techiman North District			
	Total Population	Income	Occupation	Education	Total Population	Income	Occupation	Education
Female	37024				9741			
Male	37135				8313			
very poor		130				766		
poorer		124				804		
poor		109				942		
less poor		106				884		
least poor		76				940		
Artisan			220				1530	
Businessman/woman			43				79	
Farmer			1088				2629	
Government worker			19				235	
private worker			22				359	
Student			1163				4605	
Trader			17				966	
Unemployed			346				1385	
Unavailable			764				-	
Basic education				1216				5943
JHS				504				2026
None				898				1814
secondary				276				1578
Tertiary				38				441
Unavailable				753				-

The KHDSS data also indicates that household income in Kintampo South and Techiman North ranged between 44 and 476 Ghanaian cedis which is roughly equivalent to between $6 and $66 USD. The main occupation of household members from both districts is farming. In this study, a ‘household’ is defined as a family or group of families who share a house, while a ‘community’ is a geographical boundary within the districts. The two communities are similar in terms of socio-economic status but different in terms of terrain (Figure 11).

Figure 11: Photos of rural setting and stacks of firewood in and around community setting in both districts

3.2. Sample participants

(1) Sampling procedure and sample size calculation

Recruitment of study participants was conducted from 28/01/2021 to 04/06/2021 by the author and three field workers. Over the course of recruitment in the field, a two-stage sampling technique was applied using the Kintampo Health Research Center Demographic Surveillance System (KHRC DSS). Of the six districts (Kintampo North, Kintampo South, Techiman North, Techiman South, Nkoranza North, Nkoranza South) under the KHRC DSS study areas, two districts were randomly selected: Kintampo South and Techiman North Districts (The first sampling stage). At the second sampling stage, I randomly selected two out of six gari processing communities from the Kintampo South and six out of eleven gari processing communities from the Techiman North districts. In total, eight gari processing communities were randomly selected using this method. Based on a previous study by Okwor et al. (2014) [87], a prevalence of respiratory symptoms of 6.4% and 21.9% among the comparison and worker groups was assumed, respectively. Assuming a confidence level of 95%, statistical power of 80%, and margin error of 5%, a sample size calculation suggested that a sample of 91 participants would be required in each group. Assuming 7% lost to follow-up based on previous studies [87], this resulted in 97 participants in each group of workers and community controls, i.e. a total sample of 194. The sample size calculation was performed using Stata command “sampsi” (Stata version 14, Stata Corp., College Station, Texas, USA) (see further details in Appendix B).

(2) Sampling criteria

Due to the large required sample size, stringent sampling criteria were not set. Specifically, workers needed to be engaged in stage 5 of the gari processing (i.e. cassava grits processors) for at least 12 months consecutively at the entry of this study (see Chapter 1 for an explanation of the 5-stage process). Comparisons were selected from community members who were not previously exposed to occupational biomass burning activities after matching by sex, age-group and from the same community within a given district (e.g. Atrensu - Atrensu, Ntankro – Ntankro, Aworowa – Aworowa, etc). For both workers and comparisons, potential participants were excluded if they had been previously diagnosed with COPD, chronic bronchitis, obstructive/restrictive airways disease or asthma, if they had genetic or pre-existing conditions, if they were pregnant or if they had previous history of smoking. The use of home cookstoves was not considered as a selection criteria in this study, but recorded in the questionnaire in order to adjust in the analysis.

All participants gave consent to participate in the study after understanding its purpose, procedures, risk or discomforts, benefits, confidentiality and voluntariness. All participants received a copy of their signed consent form. Participants were made aware that we needed to measure the exposure levels of the air pollutants with two devices for 48-hours (2-days) by wearing a harness across their chest, and that no harm was expected during the study. They were also informed of the benefits of the information and exposure measurements produced by the study to understand the relationship between respiratory symptoms, lung function and exposure to air pollutants. While obtaining the consent of the worker group, household number and community location were recorded as well as a contact telephone number for each participant. This enabled a smooth tracing of the same household and/or community in search of a sex- and age group-matched potential comparison member. An information sheet and consent form (Appendix C - D) was written in English. For participants under the age of 18 years, a combined information and consent form was shared with the parent or guardian for consent. Thereafter, an assent form was shared with the minor indicating their willingness to participate and understanding of the study (Appendix E - F). All these forms were in English. Although most participants were able to communicate in English, the field workers assisted in translating and explaining to participants in Twi, the language in which the target population is generally more fluent. A thumbprint option was made available to participants on the form who did not know how to sign.

3.3. Preparation in the field before data collection

(1) Training of field workers

The field work team consisted of myself (project leader), one field supervisor and three field workers, and one health personnel. The field supervisor was recruited based on scientific leadership experience in the subject area and prior experience with a similar study population, while one field worker was recruited based on previous engagement in air pollution studies and experience with a similar study population, two field workers were recruited who had no prior experience with air pollution studies. The health personnel was recruited based on expertise of conducting health assessments in various study populations.

Prior to commencing the data collection, several meetings were conducted with the field supervisor to discuss the details of the field study, including preparation of the devices for exposure monitoring, spirometry, anthropometry, blood pressure measurements and all related logistics such as travel plans from the research centre to study sites. It was vital to discuss scheduling of participant deployments for both workers and their matched comparisons within a 48-hour measuring time frame to minimize changes in weather patterns or background air pollution levels.

Memos were submitted to request tablets, laptops, field vehicle, driver and field workers to engage in data collection activities. Following memo approvals, interviews were conducted with different field worker candidates to ascertain their level of competence in relation to exposure studies and lung function studies. Three field workers were selected based on knowledge of the study areas, residence within communities in the districts, and the ability to communicate in Twi with the target population. For example, before the day of deployment, field workers would locate participants' residences and workstations within the gari sites of potential participants to attain maximum possible deployments of eight to ten participants in a given day.

The field supervisor and I conducted a 1-week training workshop with field workers to inform participants on the consent form, how to use and calibrate the exposure devices, spirometer device, and blood pressure data, including understanding the software for downloading exposure and spirometer data. One field worker had previously been engaged with the Ghana Randomized Air Pollution and Health Study (GRAPHS) and was able to share experiences with the other two field workers. This field worker with prior expertise in the study area also assisted with training fellow colleagues on familiarizing themselves with the study devices and data collection process in the study communities.

Field workers were trained on informing participants in Twi on how the harness with the exposure devices should be worn, and how to remove the harness during bathing and sleeping periods. Field workers were instructed on informing participants to place the harness a few metres away from sleeping areas but near their upper chest area. For the spirometry, field workers practiced breathing manoeuvres in Twi with supervisors. The field workers were allowed to practice with one another during the training workshop to better understand how to inform participants in Twi to blow into the flow tubes during the spirometer assessment.

(2) Gari processing site visits

We (the field supervisor, field workers and myself) visited the gari processing sites before the data collection commenced to explain the purpose of the study in Twi to both the grits fryer leaders and workers who were present at site. The supervisor and field workers wore the device harness to demonstrate how participants would wear for the 48-hour period. These visits contributed to ascertaining growing interest of leaders and workers as well as providing opportunities for potential study participants to ask questions and concerns. Furthermore, the following four questions about the cassava processing work environment were posed to leaders:

1) What is the usual work start time and end time for workers?
2) What is the usual time for the fire to start and go off at the gari frying station?
3) On which days of the week do the workers work?
4) How many workers are currently working at the gari frying station?

This information allowed the field supervisor and I to plan the study logistics in detail. Below are photos of the gari processing sites in the eight study communities:

A) Ntankro gari processing sites

B) Kwabia gari processing sites

C) Akrofrom gari processing sites

D) Aworowa gari processing site

E) Gyebiri/Krobo gari processing site

F) Atrensu gari processing site

G) Ayeasu gari processing site

Figure 12: Photos of gari processing sites in the study communities

3.4. Data collection

(1) Flow of data collection activities

Through face-to-face interviews, a standardized questionnaire was administered to all participants by experienced data collectors to collect data occurred over a period of four months from 22 February 2021 to 19 June 2021 on sociodemographic characteristics (Enrollment form), self-reported respiratory symptom form, a commercial and household cooking practices survey, an exposure monitoring survey, and a spirometer form), exposure measuring devices, blood pressure monitoring devices and a spirometer device. Data collection for each participant was conducted over four days (Figure 13). On the first day of visit to the gari processing site, the field team communicated with the cassava grits processor's community lead and the workers to explain the details of the study. After explanation in Twi, workers who agreed to enroll in the study were approached for consent and allocated as study participants.

According to information on workers' demographic and household assigned identification numbers in the gari processing communities, potential participants as matched comparisons were identified and approached on the same day. Identification of worker participants and matched comparisons were completed on the same day (Day 0) and pre-vital measurements (blood pressure, pulse, height and weight) as well as consent forms (including U18 consent and parent's consent for U18s where necessary) were collected. On the following day (Day 1) portable $PM_{2.5}$ and CO exposure devices were setup and deployed to conduct personal exposure monitoring in the following 48-hour period. Information about occupational and household cooking practices (stove type, area, duration etc.) was also collected through a standardized survey form (Appendix G).

On the third day (Day 2), the exposure monitoring survey form was completed to assess household cookstoves and cooking locations in the morning, afternoon and evening on the day on which the devices were deployed and the day after drop-off. On Day 3, the exposure devices were retrieved at the end of the 48-hour measuring period, then post-vital measurements (blood pressure and pulse) and lung function spirometry tests were performed. The exposure monitoring survey form was also completed on Day 3 to assess the use of cookstoves and cooking locations if any cooking was carried out on the morning of device pick up. At the end of Day 3, the exposure monitoring data was downloaded and devices were maintained for subsequent deployment.

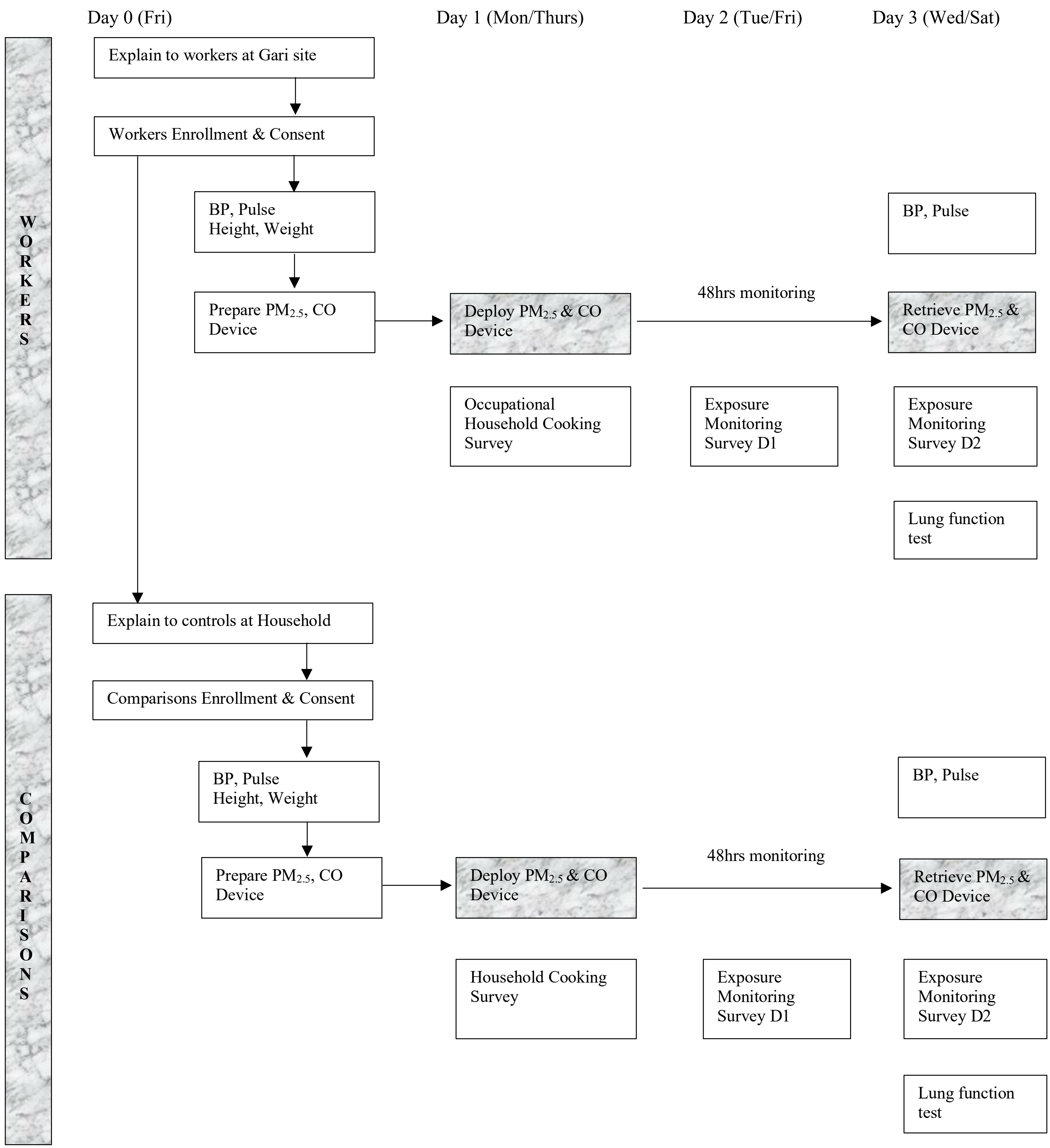


Figure 13: Flow of data collection activities

(2) Self questionnaires

The study involved three structured questionnaire forms, namely (1) an enrollment and respiratory symptom form, (2) a commercial and household cooking practices survey and (3) an exposure monitoring survey.

The enrollment and respiratory symptom form was used to collect socio-demographic characteristics, history of active and passive smoking, pre-existing respiratory symptoms and disorders, additional co-morbidities and general home cooking practice (e.g. "Do you usually cough when you do not have a cold?"; "Are there months in which you cough on most days?"; "Do you usually bring up phlegm from your chest, or do you usually have phlegm in your chest that is difficult to bring up when you don't have a cold?"; "Are you unable to walk due to a condition other than shortness of breath?") for all participants (Appendix H). The respiratory symptoms section of the form was a modified version of the American Thoracic Society Division of Lung Disease questionnaire (ATS-DLD-78) [111].

The commercial and household cooking practices survey was used to collect information on general gari processing practices at the working sites (e.g. type of stove, duration of frying activity) and home cooking practices (e.g. structure of the cooking area, type of stove, duration of cooking). This questionnaire was designed to assess participants' general exposure levels to biomass-related air pollutants during working and non-working periods (e.g. "What stove do you use most often to fry the gari?", "How many hours a day do you typically take frying gari?", "How is the structure of your household cooking area?", "What stove do you use most often in the household?", "How many hours a day do you typically cook in the household?") (Appendix G).

The exposure monitoring survey collected data regarding type and location of household cookstoves, other potential sources of exposure, and compliance during the 48-hour monitoring period (e.g. Morning meal - "Primary and secondary cookstove on the day of drop-off", "Location for primary and secondary cookstove on the day of drop-off"; Afternoon meal - "Primary and secondary cookstove on the day after drop-off", "Location for primary and secondary cookstove on the day after drop-off" "Since instrument drop off have you burned mosquito coils" "Since instrument drop off have you done trash burning?") (Appendix I).

These three questionnaires were administered using a tablet with REDCap data capture software. This software was chosen because of fast upload of questionnaires, advanced branching of questions, managing, reporting, and data import functions to a working server. Some information obtained in the enrollment and respiratory symptom form was used to exclude individuals with a smoking history or previous known history of asthma and pulmonary disease because these potential confounders may affect health outcome variables. All questionnaires used in the data collection were written in English and verbally translated into Twi. Questions were pre-tested with a small group before being administered to workers and the comparison group with the assistance of a field worker to translate.

(3) $PM_{2.5}$ and CO personal exposure measurement

$PM_{2.5}$ monitoring device

Personal exposure to $PM_{2.5}$ was monitored using Berkeley Air Monitoring Group Particle and Temperature Sensor (PATS+) devices (Figure 14). The PATS+ is a small and light weight device used to capture real-time personal $PM_{2.5}$ readings ranging from 10 µg/m^3 to 50,000 µg/m^3 at a logging rate between 2 seconds and 1 hour [112, 113]. $PM_{2.5}$ was monitored at 10 seconds intervals over a 48-hour period. The PATS+ devices were calibrated by the manufacturers internal-lab pre-use and calibrated to zero daily before and after exposure deployments using a Berkeley Air PATS+ Zero Box. The Zero Box was air-tight and had an in-built HEPA filter with a squeeze pump. This filter ensured the particle-monitoring devices were calibrated in a clean, particle-free air space. A form was also used in setting up the PATS+ device for deployment. The form contained similar questions to the Lascar form plus questions on the time and date the fire at the cookstove was put off at the end of the 48-hour measurement period (Appendix J).

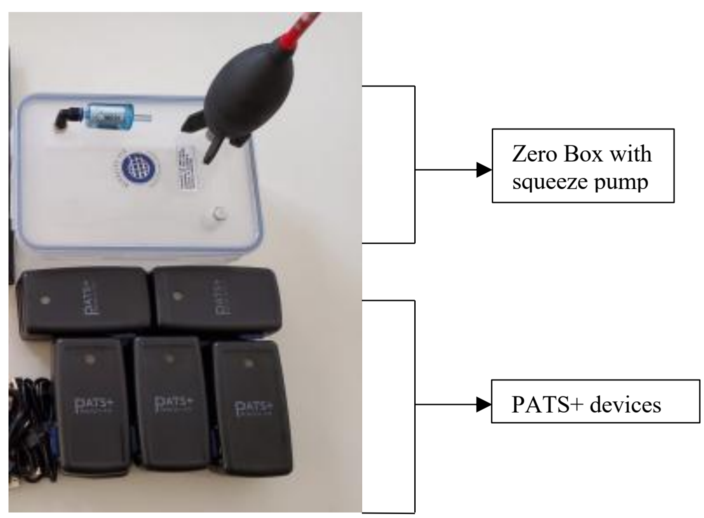


Figure 14: PATS+ devices and Zero Box with squeeze pump

CO monitoring device

Personal exposure to CO was monitored using electrochemical EL-USB-CO data loggers (Lascar EL-USB-CO) (Figure 15). The Lascar EL-USB-CO device is a lightweight monitor used to measure up to 32,510 CO readings ranging from 3 ppm up to 1000 ppm at a logging rate between 10 seconds and 5 minutes [114, 115]. Like $PM_{2.5}$, real time personal exposures were monitored at 10 second intervals over the 48-hour period.

The CO devices were calibrated by the manufacturer. A Lascar setup form was filled out prior to deployment. This form contained participant information, deployment date and time, and location of deployment (Appendix K).

Figure 15: Lascar monitor [116]

Both the Lascar EL-USB-CO and PATS+ devices were chosen because of their portable weight (42g and 110g respectively), power capacity and measuring reliability [113]. The devices were straightforward to calibrate, operate and deploy after seven-day training amongst the principal investigator and field workers. Each participant wore a harness to which both devices were attached for the 48-hour monitoring period. They were instructed to keep wearing the harness during working hours and at home with the exception of sleeping and bathing time. When sleeping and bathing, participants were informed to hang the harness within 1 meter of themselves. At the end of the real-time personal exposure monitoring, the exposure data was downloaded onto the application server and managed by the principal investigator.

(4) Lung function measurements

Spirometer device

An nDD EasyOne Air spirometer (nDD Medizintechnik AG, Switzerland) was used to assess the functioning of lungs and respiratory muscles of participants by measuring the volume of inhaled and exhaled air (Figure 16). Before each measurement, the EasyOne Air device was calibrated with an NDD 3-litre calibration syringe and once every 4 hours if the device was in use for over 4 hours [117]. For each participant, a disposable EasyOne flow tube was used to ensure hygienic testing. Breathing maneuvers were carried out with a disposable EasyOne flow tube to familiarize participants with the spirometry test.

Figure 16: EasyOne Air Spirometer and flow tubes

Lung function assessment procedure

Prior to conducting the spirometry tests, a standard spirometer questionnaire was used to collect information on participants' age, previous or current health state and recent medication use. Due to language barriers in the study communities, a trained health personnel assisted in administering the questionnaire (e.g. "Have you had an heart attack within the past three months?"; "Are you in the last trimester of pregnancy?"; "Have you had a respiratory infection (cold) in the last three weeks?; Have you taken any medications for breathing in the last 24 hours?"; "Are you unable to walk due to a condition other than shortness of breath?") and communicating the spirometry instructions to participants in Twi (Appendix L). Physical anthropometric measurements including height and weight and blood pressure and pulse were also performed with all participants in light clothing without shoes as part of the spirometer questionnaire, before measuring lung function parameters.

A trained lab personnel assisted in performing these assessments for both the worker and the comparison groups. Spirometry assessments were performed at the participants' home or near the worksite for grits fryers, depending on the participants' schedule on the assessment day. In order for participants to be familiarized with the spirometry test, breathing manoeuvres were repeated up to eight times to produce acceptable curves within 150ml or 5% of each other. Among the repeated manoeuvres, the best three acceptable curves were selected based on the following criteria: i) no hesitation at the start, indicating a rapid rise and sharp upward curve; ii) smooth upward steep peak; iii) peak is achieved in the first 25% of the forced vital capacity (FVC) manoeuvre; iv) smooth and continuous downward curve, free of artefacts; and v) curve reaches at least 6 seconds indicating termination is not early.

Lung function measurements were conducted following American Thoracic Society (ATS)/European Respiratory Society (ERS) guidelines [111]. Spirometry tests were performed around the same time of the day for workers and comparisons at the gari worksite or at home to minimise diurnal variation. This variation is based on a range of factors including diurnal differences in atmospheric temperatures that are known to affect parameters of pulmonary function [118]. The spirometry tests were performed in a standing position or in a sitting position. The participants were informed prior to the day of spirometer measurements not to eat heavy meals within 2 hours of the procedure. The procedure posed minimal risk of infection as each participant had their own EasyOne flow tube disposable mouthpiece. The spirometer device was always kept clean and dry, and disposable EasyOne flow tubes were used for each participant.

Measured lung function parameters

The measured lung function parameters included Forced Vital Capacity (FVC), Forced Expiratory Volume in the first second (FEV_1), the ratio of FEV_1/FVC, and Forced Expiratory Flow at 25% and 75% of the pulmonary volume ($FEF_{25-75\%}$). These lung function parameters are indicative of either lung volume or airways function. Briefly, FVC assesses lung volume, showing the maximum exhalation of air for the total duration of the spirometry test. FEV_1 assesses airways and lung volume, showing the maximum exhalation of air in the first second of an FVC maneuver. FEV_1/FVC ratio assesses airflow limitation, showing the percentage of FVC exhaled in one second. $FEF_{25-75\%}$ assesses large and peripheral airways, showing the average flow exhaled between 25% and 75% of the FVC [22, 119, 120].

(5) Blood pressure, pulse and anthropometric measurement

Blood pressure was measured using an A & D Medical LifeSource Blood Pressure monitor, and pulse rate and oxygen saturation of arterial hemoglobin (SpO2) was measured using a Pulse Oximeter [121, 122]. Participants' height was measured in centimeters with a height meter scale and weight was measured in kilograms with an Omron digital weight scale.

3.5. Data management

REDCap was used to create all questionnaires/forms and to collect the data using Android-based tablets. A codebook was used to understand the meaning of abbreviations and acronyms. Designed questionnaires/forms were tested with field supervisors and field workers. Stata Software version 14® [Stata Corp., College Station, Texas, USA] was used for analyses.

(1) Data storage and backup

Captured data using REDCap was checked for entry errors (e.g. incorrect date entry or wrong selection of participant group) before being securely transferred to the Kintampo Health Research Centre server. The data was downloaded and saved onto a working desktop, OneDrive, and password-protected laptop. $PM_{2.5}$ and CO personal monitoring data was downloaded using EasyLog software and PICO (Platform for Integrated Cookstove Assessment) software, and the spirometry data was downloaded through nDD EasyOne software. Downloaded data was transferred into an Excel sheet for analysis. Participants' data were anonymized. Both workers and comparisons were given participant ID numbers for allocation into either the worker or the comparison group. After anonymization, non-identifiable information was stored in the password-controlled server on the Kintampo Health Research Centre server.

(2) Data cleaning and imputation

The data was cleaned to check for further errors or inconsistencies in the downloaded data from the device software. Data cleaning also ensured multiple data entry dates and times were formatted in the same order, and measurement periods were examined to ensure data was collected every 10 seconds over the 48-hour measurement period. Seven participants had 1-minute (i.e. 60 second interval) measurements only and one had a mixture of no-second and with second-measurements only. If the data had seven records instead of six records within the same minute, then the additional record of ten seconds was dropped. All measurements for one participant with a mixture of with no-second and with second-measurement only were dropped. $PM_{2.5}$ and CO measurements were averaged by hour and minute after dealing with the Lower limit Of Detection (LOD) and the upper measurement limit stated in the specification of monitoring devices: 10 and 50,000 $\mu g/m^3$ for $PM_{2.5}$; 3 and 1000 ppm for CO. If measurements were recorded as LOD, they were halved as per the general technique in exposure studies [61, 123]. For observed measurements of $PM_{2.5}$ above the specified upper measurement limit, these were replaced with 30,000 $\mu g/m^3$ for $PM_{2.5}$. For each participant, 48 hours of data (2,880 1-minute measurements) were extracted. Two participants with less than 80% of 48-hour $PM_{2.5}$ measurements were excluded. 14 participants with less than 80% of 48-hour CO measurements were also excluded. Data entries from all questionnaire forms were checked.

3.6. Analysis

First, descriptive statistics of the study population were summarised using proportions and percentages for categorical variables and means and standard deviations (or medians and interquartile ranges) for continuous variables. Given the interest in the outlined socio-demographic factors in relation to pulmonary function abnormality, variables such as gender, smoking status, marital status, household size, education, type of home cookstove, ventilation of cooking area, hours of home cooking, duration of years in cassava industry, BMI, mosquito coil use, and trash burning were examined within the workers and comparisons groups. Stata Software version 14® [Stata Corp., College Station, Texas, USA] was used for analyses.

(1) Characterization of personal exposure to $PM_{2.5}$ and CO and examination of difference between the workers and comparison group

First, to understand the temporal fluctuations of personal exposure to $PM_{2.5}$ and CO, time plots of each participant's personal exposure were plotted by hourly average over the 48-hours. Assuming the same time of fire-on and off at gari processing site, active home hours in the worker group, home cooking hours in the comparison group, and quiet home hours for both groups for the observed two days, each hour was classified according to activity. Then, the distribution of study participants' cumulative exposure (total exposure during 48-hours) was checked before conducting statistical difference tests between groups. Depending on the distribution of cumulative exposure, either a test on means using the Student T-test (for normal distribution) or a test on medians using Nonparametric analysis methods for equality of matched pairs of observations (for skewed distribution, *signtest* in Stata) were used. After comparing the mean (or median) of $PM_{2.5}$ and CO within the 48-hours between the worker and comparisons groups, cumulative total and hour-average exposure levels were also compared between at-worksite and at-home times for the workers only.

(2) Examination of respiratory health

To answer the set of research questions under Objective 2, results from the spirometry tests and questionnaires of subjective symptoms were analysed with the primary focus on objective pulmonary function parameters. Differences in lung function parameters, namely the mean and percentage of predicted FVC, FEV_1, FEV_1/FVC, $FEF_{25-75\%}$, were compared between the workers and the comparisons group by the Student T-test for comparison of means.

Generally, spirometry indicates the presence of abnormalities in pulmonary function if: FEV_1 <80% of predicted normal, FVC <80% of predicted normal and/or FEV_1/FVC ratio <0.7 [58]. In this study, following the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria, four categories of diagnosis relating to pulmonary function were defined based on the combination of FVC, FEV_1 and FEV_1/FVC ratio and similar categories (except for normal diagnosis) were used by Oloyede et al. (2018) in their gari study [58]: an obstructive defect was implied by reduction in airflow (difficulty in exhaling air) when FEV_1 was reduced (<80% of predicted normal) with FVC reduction to some extent (i.e. FEV_1/FVC ratio <0.7); a restrictive pattern was implied by reduction in lung volume (difficulty in inhaling air into the lungs) when both FVC and FEV_1 were reduced (<80% of predicted normal) with a normal FEV_1/FVC ratio >0.7; a 'mixed' pattern, i.e. a combination of obstructive defect and restrictive pattern, when FVC was reduced (<80% of predicted normal) and FEV_1/FVC ratio was not in the normal range (<0.7); and normal lung function when FVC and FEV_1 were not reduced (>80% and >80% of predicted normal) and the FEV_1/FVC ratio stayed in the normal range (>0.7) (see Table 9) [58, 87, 124]. The percentage predicted values were calculated automatically with the EasyOne Air device according to the European standard for lung function testing [ERS (ECCS/EGKS), 1993 * 0.88] [125, 126].

Table 9: Pulmonary Function Test Interpretation

FVC	FEV_1/FVC ratio	FEV_1	Suggested diagnosis
> 80% of predicted normal	> 0.7	>80% of predicted normal	Normal
-	< 0.7	<80% of predicted normal	Obstructive defect
< 80% of predicted normal	> 0.7	<80% of predicted normal	Restrictive pattern
< 80% of predicted normal	< 0.7	-	Mixed pattern

Source: A Stepwise Approach to the Interpretation Pulmonary Function Tests [22, 58, 87, 124]

If there were indicators of an obstructive defect, a restrictive pattern or a mixed pattern, an assessment of the degree of severity of the abnormality was conducted using the American Thoracic Society grading system (Table 10) [22]. Proportions of such collective interpretations of pulmonary function measures in categories were compared between the workers and the comparisons by Chi-square or Fishers exact tests.

Table 10: American Thoracic Society Grades for Severity of a Pulmonary Function Test Abnormality

Severity	FEV_1 %pred
Mild	> 70
Moderate	60 to 69
Moderately severe	50 to 59
Severe	35 to 49
Very severe	< 35

Source: Interpretative strategies for lung function tests [22]

Self-reported respiratory symptoms (cough, phlegm, shortness of breath) were also analysed. Prevalence of subjective respiratory symptoms was compared between the worker and comparisons groups using the Chi-square test. Odds Ratios (OR) were used to quantify the magnitude of risk of respiratory symptoms and pulmonary function abnormality in the worker group compared to the comparison group. Multiple logistic regression analysis allowed the ORs to be adjusted for other important factors including marital status, education, type of home cookstove, hours of home cooking, ventilation of cooking area, and household size. In the multivariate analysis, all statistically significant socio-demographic variables (p-value of less than 0.05) in the univariate analysis and any clinically important variables which were not significant were included to test for elevated risk of pulmonary function abnormality or respiratory symptoms among the workers compared to the comparison group.

(3) Examination of association between $PM_{2.5}$ and CO exposure and respiratory health

Multiple logistic regression models were applied to test for associations between pulmonary function abnormality or symptoms and $PM_{2.5}$ and CO exposure levels. The final model was explored by including all relevant socio-economic variables that suggested statistical significance at the univariate analysis stage, plus clinically important variables with little statistical significance. The magnitude of $PM_{2.5}$ and CO effects was described as change in lung function parameters (%) and OR of pulmonary function abnormality per Interquartile range for $PM_{2.5}$ (52.04 $\mu g/m^3$) and for CO (1.76 ppb) after adjusted for other key risk factors.

3.7. Ethical compliance and approval

This study was conducted in compliance with the approved ethics proposal and adherence to all ethical principles. These principles included the autonomy of participants - respecting their rights, beneficence – doing good for the interest of participants, nonmaleficence – doing no harm to participants, and the justice of creating fairness and equality for others [127]. The study did not pose any risks to respondents but was designed to gather information in the hope of reducing workers' exposure to biomass fuels from traditional cook stoves and sustaining the environment. Personal information and anonymity of participants was respected. Participation in the study was voluntary following signed or thumb printed consent and were informed of the freewill to withdraw from the study if they wanted to (Appendix C - F).

Scientific and Ethical approval was obtained from the Kintampo Health Research Centre the Institutional Ethics Committee (KHRCIEC/2019-16; FWA00011103, Kintampo Health Research Centre Scientific Review Committee, and the London School of Hygiene and Tropical Medicine Ethics Committee (17694 /RR/21194). Ethics approval was required because the primary source of data was obtained directly from participants. After the post-COVID-19 pandemic peak phase in October 2020, data collection was permitted by the Kintampo Health Research Centre Institutional Ethics Committee and the London School of Hygiene and Tropical Medicine Ethics Committee to be carried out from February 2021. The study was funded in part with an LSHTM Research Degree Travelling Scholarship.

CHAPTER 4: RESULTS

4.1. Characteristics of study participants

194 participants (97 gari frying workers and 97 comparisons) consented to participate in the study. Table 11 shows the socio-demographic characteristics of the worker and comparison groups and the results of Chi-square test where relevant. In this study, all the workers were grits fryers who worked at stage 5 of gari processing, while the comparison group were involved in non-biomass exposed occupations such as artisans (13%), traders (35%), farmers (37%) and housewives/students (14%). More than 70% of workers have been involved in gari processing for at least a year and 60% of these workers work daily at the cookstoves for an average of 8-hours.

Most characteristics were similar among the workers and the comparisons, except marital status, education, and home cooking hours. In general, study participants were mostly female (99%), aged 14-55 years old with an average age of 33 years old. Approximately half of the study participants had lived in the same district (i.e. Kintampo South or Techiman North) for more than 10 years at the time of questionnaire survey, with a slightly higher percentage with such long residence in the comparison group (52% v 39%, not statistically significant difference). The majority of study households consisted of 6-10 family members (53%), followed by 1-5 (37%) and 11+ members (10%) with no clear difference in household size between the workers and the comparisons. 15.5% and 14.3% of the study participants were exposed to second-hand tobacco smoke in their households for the workers and the comparisons respectively.

Apparent differences between the workers and comparisons were seen in marriage status, education and some of the home cooking characteristics. The worker group consisted of a higher percentage of married females (75.3 %) than the comparisons (50.5%) (p-value of Chi-square test $p<0.001$). The workers had received less education than the comparison group, with 13% of workers having completed higher than middle or junior high school and 53% having no formal educational training (corresponding figures for the comparisons 35% and 35%, Chi-sq test $p=0.004$). This means most of the workers did not go to school or stopped schooling at the primary, middle or junior high school levels compared to the comparison group who were more likely to have been educated to the middle or junior high school level and post junior high school.

There was no statistically significant difference in the household cooking stove types used among the workers and the comparisons: nearly 60% of the study population used open mokyia stoves which comprise of 3-stone, mud or clay cookstoves (Figure 17), followed by 21% using closed mokyia (Figure 18), 17% using coal pot and 3% (the comparisons only) using gas stoves. The very limited use of gas stoves among study participants reflects the low wealth index of individuals from the selected study districts. Over 70% of the workers spent 2-hours or more cooking at home and a similar percentage (67%) was seen for the comparisons. 70% (69% for the workers, 71% for the comparison) of the participants had their cooking stoves at home in a totally open area and 5% (4% for the workers and 6% for the comparisons) had them in a fully enclosed space at home.

Figure 17: Sample picture of open mokyia cookstove [128, 129]

Figure 18: Sample picture of closed mokyia cookstove [130]

Table 11: Socio-demographic characteristics of study participants

Characteristics	Total n (%)	Workers n (%)	Comparisons n (%)	Chi-sq	p-value
All	194 (100)	97 (100)	97 (100)		
Age (years, mean ± SD)	32.6 ± 9.1	32.6 ± 8.66	32.6 ± 9.6	4.926	0.295
<20	16 (8.2)	4 (4.1)	12 (12.4)		
20-29	63 (32.5)	35 (36.1)	28 (28.9)		
30-39	63 (32.5)	33 (34.0)	30 (30.9)		
40-49	42 (21.6)	20 (20.6)	22 (22.7)		
50-59	10 (5.2)	5 (5.2)	5 (5.2)		
Sex					
Male	2 (1.0)	1 (1.0)	1 (1.0)	0.000	1.000
Female	192 (99.0)	96 (99.0)	96 (99.0)		
Marital status					
Single	72 (37.1)	24 (24.7)	48 (49.5)	12.721	<0.001
Married	122 (62.9)	73 (75.3)	49 (50.5)		
Number of years living in district					
<5	63 (32.5)	37 (38.1)	26 (26.8)	3.580	0.167
6-10	43 (22.2)	22 (22.7)	21 (21.7)		
10+	88 (45.4)	38 (39.2)	50 (51.6)		
Number of household occupants					
1-5	72 (37.1)	40 (41.2)	32 (33.0)	1.605	0.448
6-10	103 (53.1)	49 (50.5)	54 (55.7)		
11+	19 (9.8)	8 (8.3)	11 (11.3)		
Passive smoking status[1)]					
No	165 (85.1)	82 (84.5)	83 (85.6)	0.041	0.840
Yes	29 (15.0)	15 (15.5)	14 (14.3)		
Education					
None	85 (43.8)	51 (52.6)	34 (35.1)	13.068	0.004
Primary School	62 (32.0)	33 (34.0)	29 (29.9)		
Middle/Junior High School	39 (20.1)	11 (11.3)	28 (28.9)		
Post Junior High School	8 (4.1)	2 (2.1)	6 (6.2)		
Occupation					
Domestic/Student	14 (7.2)	-	14 (14.4)	-	-
Artisan	13 (6.7)	-	13 (13.4)		
Trader	34 (17.5)	-	34 (35.1)		
Farmer	36 (18.6)	-	36 (37.1)		
Gari worker	97 (50.0)	97 (100.0)	-		

(continued)

Duration years in industry					
<5 years	45 (46.39)	45 (46.39)	-	-	-
5-10 years	32 (32.99)	32 (32.99)	-		
11-20 years	14 (14.43)	14 (14.43)	-		
>20 years	6 (6.9)	6 (6.9)	-		
Type of home cookstove					
Open mokyia (3-stone/mud/clay)	117 (60.6)	62 (64.6)	55 (56.7)	4.024	0.259
Closed mokyia (metal/clay)	41 (21.2)	18 (18.8)	23 (23.7)		
Coal pot	32 (16.6)	16 (16.7)	16 (16.5)		
Gas stove	3 (1.6)	0 (0.0)	3 (3.1)		
Hours of home cooking					
1-hour	55 (28.4)	23 (23.7)	32 (33.0)	4.786	0.091
2-hours	111 (57.2)	63 (65.0)	48 (49.5)		
3-hours	28 (14.4)	11 (11.3)	17 (17.5)		
Duration hours frying gari/day					
<9 hours	62 (63.9)	62 (63.9)	-	-	-
9-12 hours	35 (36.1)	35 (36.1)	-		
Ventilation of cooking area					
Totally open outdoors (Good)	136 (70.1)	67 (69.1)	69 (71.1)	1.621	0.655
Partially enclosed (Satisfactory)	47 (24.2)	25 (25.8)	22 (22.7)		
Fully enclosed (Poor)	10 (5.2)	4 (4.1)	6 (6.2)		
None	1 (0.5)	1 (1.0)	0 (0.0)		

[1)]All non-current/historical smokers

4.2. Personal exposure to $PM_{2.5}$ and CO

(1) $PM_{2.5}$

For this study, average $PM_{2.5}$ averaged over 24-hours and 48-hours for both study groups in the Kintampo South and Techiman North districts were considerably higher than the 2005 and 2021 WHO guidelines (Table 12A). On the other hand, for CO, the average exposures were only greater than the WHO guidelines in the worker group in the Kintampo South district (Table 12B).

Table 12A: Average study $PM_{2.5}$ measurements and WHO air quality guidelines

Pollutant	Averaging time	Average study concentrations		2005 WHO Guideline AQG levels	2021 WHO Guideline AQG levels
$PM_{2.5}$, μg/m³	48-hour	All Workers	All Comparisons	10 μg/m³*	5 μg/m³*
		94.64 μg/m³	41.27 μg/m³		
		Kintampo	Kintampo		
		99.06 μg/m³	51.99 μg/m³		
		Techiman	Techiman		
		92.42 μg/m³	35.92 μg/m³		
	24-hour	All Workers	All Comparisons	25 μg/m³	15 μg/m³
		108.85 μg/m³	41.22 μg/m³		
		Kintampo	Kintampo		
		120.68 μg/m³	53.38 μg/m³		
		Techiman	Techiman		
		102.93 μg/m³	35.13μg/m³		

* WHO long-term guideline refers to annual average exposure

Table 12B: Average study CO measurements and WHO air quality guidelines

Pollutant	Averaging time	Average study concentrations		2005 WHO Guideline AQG levels	2021 WHO Guideline AQG levels
CO, ppm	24-hour	All Workers	All Comparisons	7 μg/m³ (6.11 ppm)	4 μg/m³ (3.49 ppm)
		5.92 ppm	1.96 ppm		
		Kintampo	Kintampo		
		10.40 ppm	1.91 ppm		
		Techiman	Techiman		
		3.67 ppm	1.99 ppm		

The overall distribution of hourly-average $PM_{2.5}$ concentrations from 48-hours of observation is slightly skewed towards 0 μg/m³ (Figure 19), suggesting a Wilcoxon rank-sum (Mann-Whitney) test is required to test the differences of the medians between sub-groups.

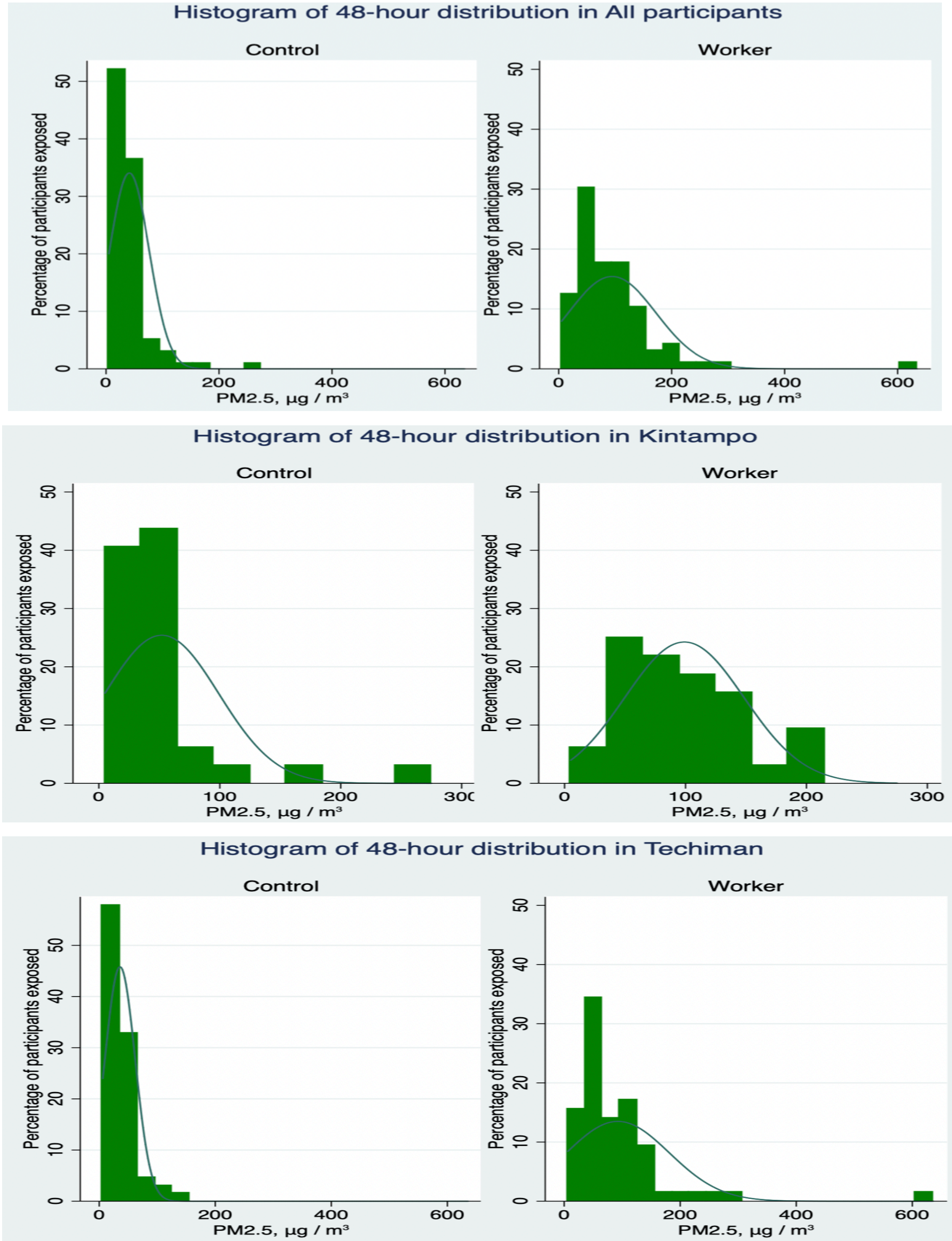


Figure 19: Histogram of hourly-average $PM_{2.5}$ concentration during 48-hours for workers and comparisons in both districts (top), Kintampo district (middle), Techiman district (bottom). X-axis are limited to 600 µg/m³.

A summary of $PM_{2.5}$ hourly-average exposure for gari workers and comparisons in both districts and district-specific subgroups is shown in Table 13. The average measured $PM_{2.5}$ concentration ranged from the lowest observable value by the device [5 μg/m^3, half the LOD] to 625 μg/m^3 for gari-workers and 259 μg/m^3 for the comparisons. Overall, the median $PM_{2.5}$ exposure for all observation hours was higher for the workers than the comparisons: 76.2 (IQR 52.3-118.5) vs. 33.7 (IQR 19.7-52.5) μg/m^3 (Wilcoxon rank-sum test Prob >|z| = 0.0000). This was true in both the Techiman North and Kintampo South districts (Wilcoxon rank-sum Prob >|z| = 0.0000).

When looking only at gari-frying hours among workers, the median $PM_{2.5}$ exposure decreases slightly by 10 μg/m^3 to 66.1 (IQR 54.3-102.3) μg/m^3 in both districts with a higher level in Kintampo South than Techiman North. This median exposure is high considering that the gari-workers in these districts generally spend 8 hours on average daily at the frying station. Among gari-workers, overall $PM_{2.5}$ exposure was highest during quiet home hours (Wilcoxon rank-sum test Prob >|z| = 0.0000). Similar exposure was observed for active home hours during assumed home-cooking hours (median (IQR): 72.9 (45.7-117.4) μg/m^3) but increased for quiet home hours (106.3 (52.3-138.7) μg/m^3) (Wilcoxon rank-sum test suggested non-statistical difference in median for active home hours).

Table 13: Summary of $PM_{2.5}$ hourly-average exposure (μg/m^3) among study participants by district

	Hourly average $PM_{2.5}$ exposure (μg/m^3)					
	All		Kintampo South		Techiman North	
	Workers	Comparisons	Workers	Comparisons	Workers	Comparisons
Whole 48 hours						
Min-Max	5.0-625.0	5.1-259.0	5.0-210.7	5.1-259.0	11.5-625.0	6.2-135.0
Median (IQR) [1]	76.2 (52.3, 118.5)	33.7 (19.7, 52.5)	90.7 (59.5, 131.0)	39.4 (28.7, 57.3)	66.7 (44.8, 113.9)	31.7 (15.9, 49.3)
Wilcoxon rank-sum test	Prob > |z| = 0.0000		Prob > |z| = 0.0000		Prob > |z| = 0.0000	
Gari frying hours						
Min-Max	15.2-168.0	-	55.2-168.0	-	15.2-155.5	-
Median (IQR) [1]	66.1 (54.3, 102.3)	-	93.2 (63.9, 104.1)	-	57.2 (40.5, 86.9)	-
Active home hours/ Home cooking hours [2]						
Min-Max	5.0-625.0	15.4-81.0	5.0-150.5	5.1-109.0	27.3-625.0	15.4-81.0
Median (IQR) [1]	72.9 (45.7, 117.4)	51.3 (31.9, 59.7)	77.4 (53.9, 119.7)	47.5 (31.6, 58.6)	71.0 (40.5, 115.1)	46.3 (31.9, 57.1)
Wilcoxon rank-sum test	Prob > |z| = 0.0923		Prob > |z| = 0.8848		Prob > |z| = 0.1153	
Quiet home hours						
Min-Max	11.5-303.3	5.1-259.0	50.4-210.7	5.1-259.0	11.5-303.3	6.2-135.0
Median (IQR) [1]	106.3 (52.3, 138.7)	33.2 (19.6, 49.6)	127.9 (91.5, 196.2)	38.8 (26.6, 56.2)	87.6 (52.3, 123.0)	29.3 (15.7, 47.8)
Wilcoxon rank-sum test	Prob > |z| = 0.0000		Prob > |z| = 0.0009		Prob > |z| = 0.0000	

[1] IQR is represented by the 25th percentile and 75th percentile values.

[2] Home cooking hours for Comparisons and active home hours (after work until sunset at 8pm) for workers.

(2) CO

The distribution of hourly-average CO concentration from the 48-hour observations was again slightly skewed towards 0 ppm (Figure 20), suggesting the Wilcoxon rank-sum (Mann-Whitney) test is required to test differences in medians between sub-groups.

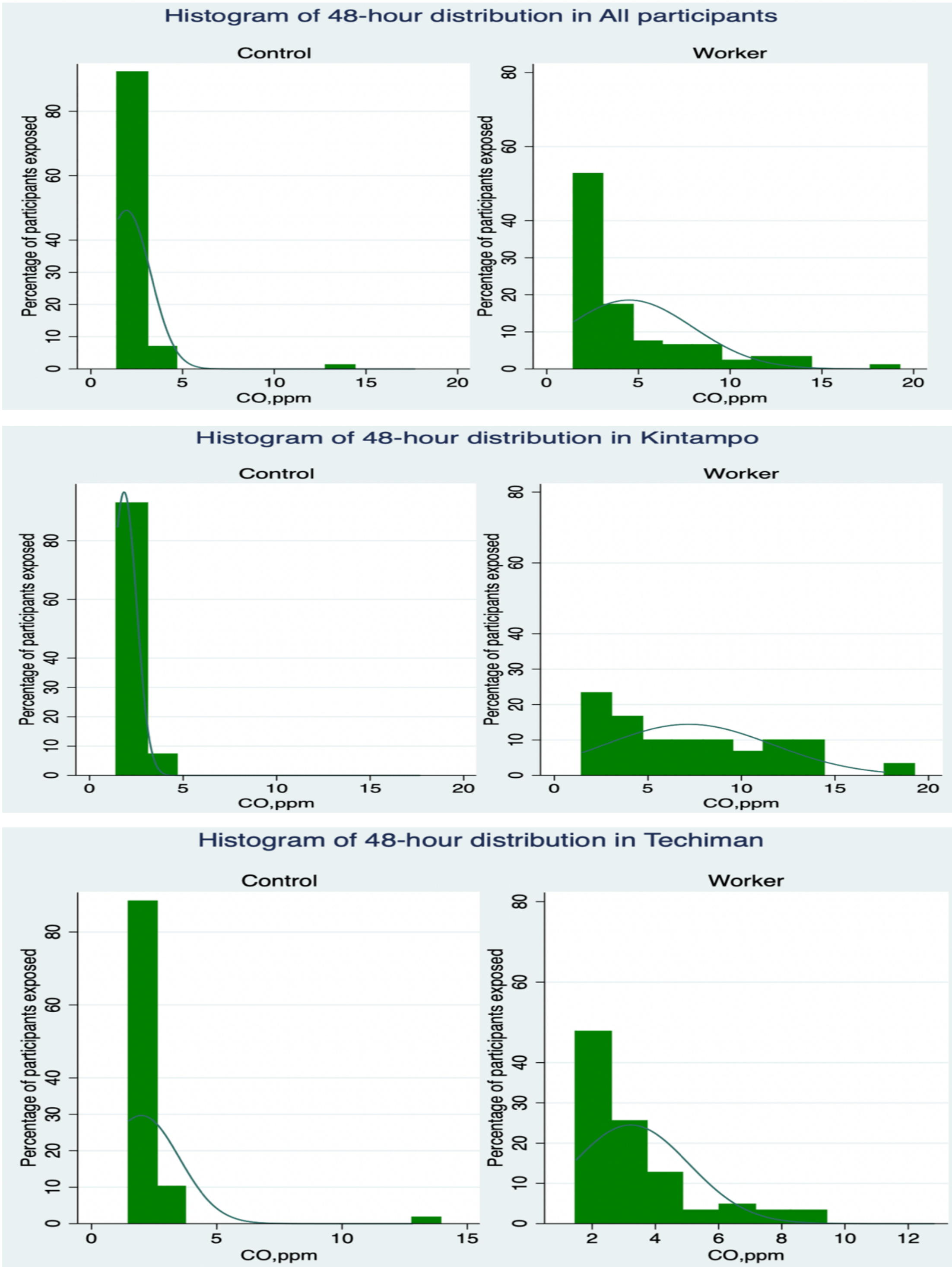


Figure 20: Histogram of hourly-average CO concentration during 48-hours for workers and comparisons in both districts (top), Kintampo district (middle), Techiman district (bottom). X-axis was up to 20ppm.

A summary of hourly-average CO exposure for gari workers and comparisons in both districts and district-specific subgroups is shown in Table 14. The average measured CO concentration ranged from the lowest observable value by the device [1.5 ppm, half the LOD] to 17.7 ppm for gari-workers and 12.8 ppm for the comparisons. Overall, the median CO exposure for all observation hours was slightly higher for the workers compared to the comparisons: 3.1 (IQR 2.1-5.9) vs. 1.6 (1.5-1.8) ppm (Wilcoxon rank-sum test Prob >|z| = 0.0000). This was true in the Techiman North district, but the median was higher in Kintampo South (Wilcoxon rank-sum Prob >|z| = 0.0000).

The median CO exposure during gari frying hours among workers was 2.9 ppm (IQ 1.9-4.3) in both districts, with higher levels in Kintampo South than in Techiman North. Among gari workers, overall CO exposure was highest during active home hours (median (IQR): 3.4 (2.7-7.1) ppm) and slightly lower for quiet home hours (2.7 (1.8-6.2) ppm) (both Wilcoxon rank-sum test suggested statistical differences in medians).

Table 14: Summary of CO hourly-average exposure (ppm) among study participants by district

	Hourly average CO exposure (ppm)					
	All		Kintampo South		Techiman North	
	Workers	Comparisons	Workers	Comparisons	Workers	Comparisons
Whole 48 hours						
Min-Max	1.5-17.7	1.5-12.8	1.5-17.7	1.5-4.5	1.5-8.7	1.5-12.8
Median (IQR) [1)]	3.1 (2.1, 5.9)	1.6 (1.5, 1.8)	6.8 (3.3, 9.9)	1.6 (1.5, 1.7)	2.7 (1.9, 3.9)	1.5 (1.5, 1.8)
Wilcoxon rank-sum test	Prob > |z| = 0.0000		Prob > |z| = 0.0000		Prob > |z| = 0.0000	
Gari frying hours						
Min-Max	1.5-14.1	-	2.1-14.1	-	1.5-5.7	-
Median (IQR) [1)]	2.9 (1.9, 4.3)	-	7.8 (4.3, 11.3)	-	2.2 (1.8, 3.0)	-
Active home hours/ Home cooking hours [2)]						
Min-Max	1.5-17.7	1.5-3.3	2.4-17.7	1.5-3.2	1.5-8.7	1.5-3.3
Median (IQR) [1)]	3.4 (2.7, 7.1)	1.5 (1.5, 2.5)	8.8 (4.1, 12.3)	2.4 (1.5, 3.2)	2.9 (2.4, 4.3)	1.5 (1.5, 2.5)
Wilcoxon rank-sum test	Prob > |z| = 0.0004		Prob > |z| = 0.0857		Prob > |z| = 0.0018	
Quiet home hours						
Min-Max	1.5-11.3	1.5-12.8	1.5-11.3	1.5-4.5	1.5-8.4	1.5-12.8
Median (IQR) [1)]	2.7 (1.8, 6.2)	1.6 (1.5, 1.8)	4.0 (2.0, 9.2)	1.6 (1.5, 1.8)	2.3 (1.8, 4.1)	1.5 (1.5, 1.8)
Wilcoxon rank-sum test	Prob > |z| = 0.0000		Prob > |z| = 0.0013		Prob > |z| = 0.0001	

[1)] IQR is represented by the 25th percentile and 75th percentile values.

[2)] Home cooking hours for Comparisons and active home hours (after work until sunset at 8pm) for workers

4.3. Lung function

(1) Lung function parameters

Lung function indices (FEV_1, FVC, FEV_1/FVC, $FEF_{25-75\%}$) were explored independently among gari workers and comparisons and in relation to the following factors: gender, marital status, number of years in district, household size, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning and mosquito coil use. Examination of the overall distributions among all study participants suggested that FEV_1, FVC and $FEF_{25-75\%}$ were normally distributed: FEV_1% of predicted ranged from 9% to 111% with a mean of 65% and median of 66%; FVC% of predicted ranged from 10% to 154% and the mean and median 79%; $FEF_{25-75\%}$ % of predicted (range 3% to 105%) with mean 39% and median 38%. The ratio of FEV_1/FVC ranged from 26% to 119% and was negatively skewed and the mean (85%) was below the median (91%). Most participants were observed to be within the 25^{th} and 75^{th} percentile for FEV_1% predicted, FVC% predicted and $FEF_{25-75\%}$ predicted.

Table 15 reports lung function parameters for the worker and comparison groups. FEV_1% and FVC% were statistically higher in terms of mean±SD for gari workers compared to the comparisons: 68.00 ± 22.62% vs 61.09 ± 18.77% and 83.32 ± 21.48% vs 74.76 ± 17.58% (both $p \leq 0.05$). There was no statistically significant difference in the ratio of FEV_1/FVC and $FEF_{25-75\%}$ between the worker and comparison groups.

Table 15: Lung function parameters (mean±SD) of the study participants by the comparison and worker group

	Workers n = 97	**Comparisons n = 97**	**t**	***P value***
FEV_1 (L)	1.60 ± 0.06	1.46 ± 0.49	-1.97	0.050*
FVC (L)	2.25 ± 0.63	2.04 ± 0.56	-2.44	0.016*
FEV_1/FVC	0.71 ± 0.13	0.72 ± 0.14	0.56	0.578
$FEF_{25-75\%}$ (L/S)	1.48 ± 0.73	1.34 ± 0.70	-1.39	0.166
FEV_1 % of predicted [1)]	68.00 ± 22.62	61.09 ± 18.77	-2.31	0.022*
FVC % of predicted [1)]	83.32 ± 21.48	74.76 ± 17.58	-3.04	0.003*
FEV_1/FVC % percentage of predicted [1)]	85.07 ± 18.65	85.68 ± 19.33	0.22	0.824
$FEF_{25-75\%}$ % of predicted [1)]	41.03 ± 20.40	36.85 ± 20.41	-1.43	0.155

[1)] Reference value was predicted based on according to the European standard for lung function testing [ERS (ECCS/EGKS), 1993 * 0.88]

The higher FEV_1% and FVC% among the workers compared to the comparisons stayed significant after adjustment for home cooking stove type (open mokyia (3-stone/mud/clay), closed mokyia (metal/clay), gas stove and coal pot), ventilation of cooking area (totally open outdoors, partially enclosed, fully enclosed or no cooking area), home cooking hours (1 hr, 2 hr or 3+hrs), education level (none, primary school, middle or junior high school or post-junior high school), trash burning, mosquito coil use and the other aforementioned factors (Table 16). FEV_1 and FVC of predicted for the workers was 6.91 (95%CI: 1.02-12.79) and 8.56 (95%CI: 3.00-14.12) higher for the worker group than the comparison group and remained higher after adjusting for covariates.

Table 16: Difference in lung function parameters among the workers compared to the comparisons after adjusted for covariates, Coefficient (95%CI) of workers in reference to comparisons

	Crude model	Adjusted model[1)]
FEV_1 % of predicted	6.91 (1.02, 12.79)	7.88 (0.99, 14.78)
FVC % of predicted	8.56 (3.00, 14.12)	9.53 (3.22, 15.83)
FEV_1/FVC % percentage of predicted	-0.61 (-5.99, 4.77)	-0.74 (-7.04, 5.57)
$FEF_{25\text{-}75\%}$ % of predicted	4.19 (-1.59, 9.97)	5.56 (-1.14, 12.26)

[1)] Adjusted for gender, marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

(2) Assessment of pulmonary function

Table 17 shows the prevalence of lung function abnormalities in the worker and comparison groups as well as odds ratios (ORs) of each defined abnormality among the workers compared to the comparisons. 16.49% of workers and 15.46% of comparisons had an obstructive lung defect, which suggests little difference in the prevalence of obstructive lung defects between the two groups. An apparent difference in the prevalence of restrictive patterns was seen, however: the comparison group had a higher prevalence of restrictive pattern (52.58%) than the worker group (31.96%) (Chi-square test $p<0.01$). The OR of restrictive pattern for the workers vs comparisons was statistically significant (0.42, 95%CI: 0.24-0.76) and this stayed significant (0.35, 95%CI: 0.17-0.72) even after adjustment for covariates. For mixed pattern lung abnormalities, the prevalence among workers and comparisons was similar: 9.28% of workers and 10.31% of comparisons.

Table 17: Types of lung function abnormalities among study participants

Lung function abnormalities	Comparisons n=97, n (%)	Workers n=97, n (%)	x	*p*	Crude OR [1)] (95% CI)	Adjusted OR [1) 2)] (95% CI)
Obstructive defect						
Present	15 (15.46%)	16 (16.49%)	0.038	0.845	1.08 (0.50, 2.33)	1.29 (0.51, 3.27)
Absent	82 (84.54%)	81 (83.51%)				
Restrictive pattern						
Present	51 (52.58%)	31 (31.96%)	8.450	0.004*	0.42 (0.24, 0.76)	0.35 (0.17, 0.72)
Absent	46 (47.42%)	66 (68.04%)				
Mixed pattern						
Present	10 (10.31%)	9 (9.28%)	0.058	0.809	0.89 (0.34, 2.30)	0.80 (0.25, 2.54)
Absent	87 (89.69%)	88 (90.72%)				

*p<0.01.

[1)] OR: Odd ratio of lung function abnormality for workers compared to the comparisons.

[2)] Adjusted for gender, marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

(3) Lung function severity

Based on FEV_1% of predicted values, the severity of pulmonary function defects was defined using two categories: 'Mild to Moderately severe' and 'Severe to Very severe' (Table 18). Approximately one quarter of the participants had a Severe to Very severe pulmonary function abnormality but there was little difference in the prevalence between the two groups: 22.68% of the workers and 24.74% of the comparisons. The crude OR of Severe to Very severe pulmonary functions was not statistically significant: 0.89 (95%CI: 0.46, 1.73) and neither were the district-specific ORs.

Table 18: Grades for Severity of a Pulmonary Function (PF) Test Abnormality in the comparison (n=97) and worker (n=97) group

District	PF test severity[1)]	Comparisons n (%)	Workers n (%)	Chi2	*p*	Crude OR[2)] (95%CI)	Adjusted OR[2) 3)] (95%CI)
All	Mild to Moderately severe	73 (75.26%)	75 (77.32%)	0.114	0.736	0.89	1.03
	Severe to Very severe	24 (24.74%)	22 (22.68%)			(0.46, 1.73)	(0.47, 2.25)
Kintampo	Mild to Moderately severe	27 (84.38%)	23 (71.88%)	1.463	0.226	2.11	5.57
	Severe to Very severe	5 (15.62%)	9 (28.12%)			(0.62, 7.20)	(0.27, 125.81)
Techiman	Mild to Moderately severe	46 (70.77%)	52 (80.00%)	1.493	0.222	0.61	0.64
	Severe to Very severe	19 (29.23%)	13 (20.00%)			(0.27, 1.36)	(0.22, 1.88)

1) Mild to Moderately severe is FEV_1% of predicted 50+; Severe to Vary severe is FEV_1% <50.

2) OR: Odd ratio of lung function abnormality for workers compared to the comparisons.

3) Adjusted for gender, marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

4.4. Prevalence of self-reported respiratory symptoms

Table 19A shows the prevalence of self-reported symptoms of cough, phlegm and shortness of breath amongst participants. Overall, cough was the most reported symptom, followed by phlegm and shortness of breath. The worker group had slightly higher prevalence of cough (22.7%) than the comparison group (16.5%), but the difference was not statistically significant (p-value of Chi-square test 0.278). Neither phlegm nor shortness of breath showed a difference in prevalence between the workers and comparisons.

Table 19A: Self-reported respiratory symptoms of participants (97 workers and 97 comparisons)

Symptoms	Comparison n (%)	Workers n (%)	Chi2	*p*	Crude OR[1)] (95% CI)	Adjusted OR[1) 2)] (95%CI)
Cough	16 (16.5)	22 (22.7)	1.1781	0.278	1.49 (0.73, 3.04)	2.29 (0.91, 5.76)
Phlegm	10 (10.3)	9 (9.3)	0.0583	0.809	0.89 (0.34, 2.30)	0.95 (0.29, 3.14)
Shortness of breath	3 (3.1)	2 (2.1)	0.2053	0.650	0.66 (0.11, 4.04)	0.19 (0.01, 3.87)

1) OR: Odd ratio of symptom for workers compared to the comparisons.

2) Adjusted for gender, marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

49 (50.5%) of the study participants experienced at least one of the three respiratory symptoms (cough, phlegm and short of breath) (Table 19B). Workers had slightly higher prevalence of at least one of these symptoms than comparisons (27.8% vs 22.7%). Although the point estimate OR after adjustment for other potential risk factors suggested workers may have higher prevalence of any of these respiratory symptoms compared to comparisons, it was not statistically significant and the confidence interval was wide (OR 2.24, 95%CI: 0.96, 5.24). Other risk factors investigated here did not show statistically significant impacts on the prevalence of any respiratory symptoms, except hours of household cooking (3-hrs), BMI (above obesity), and the use of coal pot for cooking. The results showed the longer the household cooking hours, the higher the risk of these respiratory symptoms. Specifically, participants with three hours of home cooking had 5.06 (95%CI: 1.37, 18.64) times higher risk of experiencing these respiratory symptoms compared to those who cook for one hour at home.

Table 19B: Self-reported respiratory symptoms (any of cough, phlegm, short of breath) of participants (n=194) and determinants

Variables	Any respiratory Symptom Yes (n=49) n (%)	No (n=145) n (%)	Adjusted OR[1)] (95% CI)
Comparisons (n=97)	22 (22.7)	75 (77.3)	1.00
Workers (n=97)	27 (27.8)	70 (72.2)	2.24 (0.96, 5.24)
Marital status			
Married	31 (25.4)	91 (74.6)	1.00
Single	18 (25.0)	54 (75.0)	1.86 (0.75, 4.63)
Education			
None	23 (27.1)	62 (72.9)	1.00
Primary School	15 (24.2)	47 (75.8)	0.62 (0.24, 1.62)
Middle/JHS	8 (20.5)	31 (79.5)	0.42 (0.12, 1.39)
Post JHS	3 (37.5)	5 (62.5)	2.45 (0.35, 17.05)
Type of home cookstove			
Open mokyia (3-stone/mud/clay)[2)]	29 (24.8)	88 (75.2)	1.00
Closed mokyia (metal/clay)	15 (36.6)	26 (63.4)	1.21 (0.38, 3.84)
Coal pot	4 (12.5)	28 (87.5)	0.23 (0.06, 0.90)
Gas stove	1 (33.3)	2 (66.7)	0.81 (0.05, 13.76)
Hours of home cooking			
1-hour	8 (14.6)	47 (85.5)	1.00
2-hours	32 (28.8)	79 (71.2)	2.23 (0.85, 5.85)
3-hours	9 (32.1)	19 (67.9)	5.06 (1.37, 18.64)
Ventilation of cooking area			
Totally open outdoors (Good)	32 (23.5)	104 (76.5)	1.00
Partially enclosed (Satisfactory)	15 (31.9)	32 (68.1)	1.87 (0.61, 5.70)
Fully enclosed (Poor)	2 (20.0)	8 (80.0)	0.74 (0.10, 5.42)
Number of household occupants			
1-5 persons	13 (18.1)	59 (81.9)	1.00
6-10 persons	29 (28.2)	74 (71.8)	1.99 (0.83, 4.75)
More than 11 persons	7 (36.8)	12 (63.2)	2.71 (0.67, 10.97)
Number of years in district			
1-5 years	13 (20.63)	50 (79.37)	1.00
6-10 years	12 (27.91)	31 (72.09)	1.03 (0.35, 3.05)
Above 10 years	24 (27.27)	64 (72.73)	1.00 (0.39, 2.53)

(continued)

BMI			
18.5-24.9kg/m^2 Normal	23 (21.90)	82 (78.10)	1.00
<18.5kg/m^2 Underweight	1 (6.25)	15 (93.75)	0.13 (0.01, 1.33)
25-29.9kg/m^2 Overweight	16 (28.07)	41 (71.93)	1.56 (0.64, 3.77)
30kg/m^2 and Above Obesity	9 (56.25)	7 (43.75)	6.70 (1.81, 24.87)
Passive smoking			
No	40 (24.24)	125 (75.76)	1.00
Yes	9 (31.03)	20 (68.97)	1.92 (0.65, 5.63)
Trash burning			
No	37 (26.24)	104 (73.76)	1.00
Yes	12 (22.64)	41 (77.36)	1.06 (0.44, 2.53)
Mosquito coil use			
No	37 (27.61)	97 (72.39)	1.00
Yes	12 (20.00)	48 (80.00)	1.64 (0.67, 4.00)

1) Odds Ratios adjusted for gender (omitted from table because of collinearity), marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

2) Open mokyia was chosen as reference because of large sample size compared to coal pot.

4.5. Associations between air pollution exposure and lung function

Table 20A suggests little evidence of associations between IQR change in $PM_{2.5}$ exposure and change in among study participants investigated in this study in both crude and adjusted models. The regression coefficients for all participants suggest an IQR increment (52.04 µg/m^3) in minute-mean $PM_{2.5}$ exposure level is associated with 0.43% (-2.22%, 3.07%), 1.33% (-1.11%, 3.76%), -1.04% (-3.42%, 1.34%) and 1.16% (-1.28%, 3.60%) change of FEV_1, FVC, FEV_1/FVC and FEF_{25-75} as percentage of the predicted value, respectively, after adjusting for gender, marital status, numbers of years living in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use, wide confidence intervals overlapping the null association (0) makes it difficult to interpret the results. In the adjusted model, negative point estimates for FEV_1/FVC% in all, workers and comparison group suggest very weak evidence of the association between $PM_{2.5}$ and FEV_1/FVC%. However, it is the only measure among those tested in this analysis.

Most of the associations between $PM_{2.5}$ and lung function parameters investigated in this study are similar between workers and comparison groups, except FVC%, for which group coefficients are statistically different in both crude and adjusted analyses (p=0.01 and p=0.03): workers 1.53% (-0.88%, 3.94%) vs controls -3.88% (-9.12%, 1.36%) difference per an IQR increment in minute-mean $PM_{2.5}$ exposure (Table 20A and Figure 21A). This may suggest weak evidence that $PM_{2.5}$ exposure may affect detrimentally some lung functions among comparison group, but not for workers group. However, these wide confidence intervals need to be carefully interpreted.

Table 20A: Associations between <u>minute-average PM$_{2.5}$</u> exposure and lung function parameters for all, workers and comparison groups

		Crude β[1] (95%CI)	*p-value for test of equality in group β*	Adjusted β[1) 2)] (95%CI)	*p-value for test of equality in group β*
FEV$_1$, ml					
	All	0.03 (-0.03, 0.09)	-	0.02 (-0.04, 0.09)	-
	Workers	0.03 (-0.03, 0.09)	0.1679	0.03 (-0.04, 0.09)	0.0948
	Comparisons	-0.05 (-0.19, 0.08)		-0.08 (-0.22, 0.06)	
FVC, ml					
	All	0.06 (-0.01, 0.13)	-	0.06 (-0.01, 0.13)	-
	Workers	0.06 (-0.00, 0.13)	0.0810	0.07 (-0.01, 0.14)	0.0538
	Comparisons	-0.06 (-0.21, 0.09)		-0.08 (-0.24, 0.08)	
FEV$_1$/FVC, %					
	All	-0.01 (-0.02, 0.01)	-	-0.01 (-0.03, 0.01)	-
	Workers	-0.01 (-0.02, 0.01)	0.5002	-0.01 (-0.03, 0.01)	0.6921
	Comparisons	0.00 (-0.03, 0.04)		-0.00 (-0.04, 0.03)	
FEF $_{25-75}$, ml/S					
	All	0.04 (-0.04, 0.12)	-	0.03 (-0.06, 0.12)	-
	Workers	0.04 (-0.04, 0.12)	0.3414	0.03 (-0.06, 0.12)	0.1460
	Comparisons	-0.04 (-0.22, 0.14)		-0.10 (-0.29, 0.10)	
FEV$_1$%					
	All	1.21 (-1.15, 3.57)	-	0.43 (-2.22, 3.07)	-
	Workers	1.29 (-1.06, 3.64)	0.0842	0.59 (-2.04, 3.23)	0.0967
	Comparisons	-2.94 (-8.22, 2.33)		-3.88 (-9.60, 1.85)	
FVC%					
	All	1.86 (-0.38, 4.10)	-	1.33 (-1.11, 3.76)	-
	Workers	1.96 (-0.26, 4.17)	0.0148*	1.53 (-0.88, 3.94)	0.0286*
	Comparisons	-3.69 (-8.66, 1.28)		-3.88 (-9.12, 1.36)	
FEV$_1$/FVC % of predicted %					
	All	-0.45 (-2.58, 1.68)	-	-1.04 (-3.42, 1.34)	-
	Workers	-0.47 (-2.61, 1.67)	0.6527	-1.07 (-3.46, 1.32)	0.7643
	Comparisons	0.53 (-4.27, 5.33)		-0.34 (-5.53, 4.85)	
FEF $_{25-75}$ %					
	All	1.46 (-0.84, 3.75)	-	1.16 (-1.28, 3.60)	-
	Workers	1.49 (-0.81, 3.79)	0.3711	0.96 (-1.59, 3.51)	0.2330
	Comparisons	-0.64 (-5.80, 4.51)		-2.14 (-7.68, 3.40)	

[1)] Coefficient (β) of regression analysis. Difference in lung function parameters per IQR minute-average increment of PM$_{2.5}$.

[2)] adjusted for gender, marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

*p-value for test of equality in group β, $p<0.05$

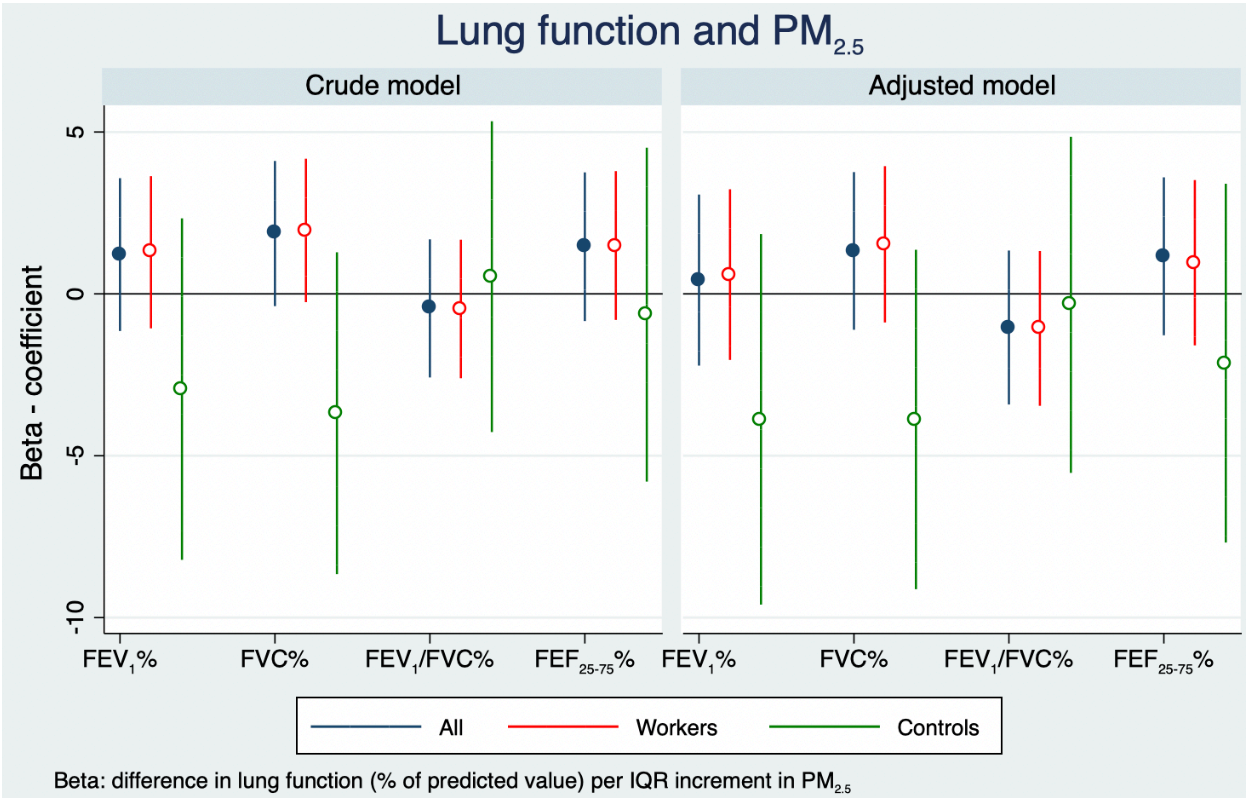


Figure 21A: Difference in lung function (% of the predicted value) per IQR increment in $PM_{2.5}$

Similarly, Table 20B shows results for CO, suggesting little evidence of associations with lung function parameters. According to the point estimates, an IQR increment in minute-mean CO exposure level (1.76 ppb) was associated with a decrease in FEV_1% and FVC% for controls group only in both crude and adjusted models. There is a significant difference in coefficients for FVC% between workers and comparisons: 0.69% (-1.08%, 2.46%) increase in workers and 5.04% (9.36%, 0.73%) decrease in comparisons group. The negative point estimates suggest possible detrimental impacts on FVC% in the comparison group. FEV_1/FVC%, there is no group difference in the estimated coefficients with CO exposure level.

Table 20B: Associations between minute-average CO exposure and lung function parameters for all, workers and comparisons group

	Crude $\beta^{1)}$ (95%CI)	*p-value for test of equality in group β*	Adjusted $\beta^{1)\ 2)}$ (95%CI)	*p-value for test of equality in group β*
FEV_1, ml				
All	0.00 (-0.04, 0.05)	-	0.02 (-0.03, 0.07)	-
Workers	0.00 (-0.04, 0.05)	0.0486	0.02 (-0.03, 0.06)	0.0229*
Comparisons	-0.10 (-0.21, 0.01)		-0.11 (-0.22, 0.01)	
FVC, ml				
All	-0.01 (-0.06, 0.13)	-	0.01 (-0.05, 0.06)	-
Workers	-0.01 (-0.06, 0.04)	0.0017*	0.01 (-0.05, 0.06)	0.0008*
Comparisons	-0.19 (-0.32, -0.07)		-0.20 (-0.33, -0.07)	
FEV_1/FVC, %				
All	0.00 (-0.01, 0.01)	-	0.00 (-0.01, 0.02)	-
Workers	0.00 (-0.01, 0.01)	0.0548	0.00 (-0.01, 0.02)	0.1086
Comparisons	0.03 (-0.00, 0.06)		0.03 (-0.00, 0.06)	
FEF_{25-75}, ml/S				
All	0.02 (-0.04, 0.08)	-	0.04 (-0.03, 0.10)	-
Workers	0.02 (-0.04, 0.08)	0.5595	0.03 (-0.03, 0.10)	0.3247
Comparisons	-0.02 (-0.18, 0.13)		-0.04 (-0.20, 0.12)	
FEV_1%				
All	1.31 (-0.47, 3.08)	-	1.36 (-0.60, 3.31)	-
Workers	1.23 (-0.54, 3.00)	0.0895	1.34 (-0.60, 3.28)	0.1187
Comparisons	-2.23 (-6.67, 2.22)		-2.07 (-6.80, 2.66)	
FVC%				
All	0.91 (-0.78, 2.61)	-	0.72 (-1.09, 2.53)	-
Workers	0.79 (-0.88, 2.45)	0.0029*	0.69 (-1.08, 2.46)	0.0044*
Comparisons	-4.95 (-9.14, -0.77)		-5.04 (-9.36, -0.73)	
FEV_1/FVC % of predicted %				
All	0.88 (-0.73, 2.48)	-	1.14 (-0.62, 2.91)	-
Workers	0.95 (-0.65, 2.55)	0.0799	1.16 (-0.59, 2.91)	0.0744
Comparisons	4.17 (0.15, 8.18)		4.68 (0.42, 8.94)	
FEF_{25-75} %				
All	1.34 (-0.39, 3.07)	-	1.58 (-0.30, 3.46)	-
Workers	1.33 (-0.41, 3.06)	0.7823	1.58 (-0.31, 3.46)	0.7343
Comparisons	0.78 (3.58, 5.14)		0.86 (-3.73, 5.45)	

1) Coefficient (*β*) of regression analysis. Difference in lung function parameters per IQR minute-average increment of CO.

2) adjusted for gender, marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

*p-value for test of equality in group β, $p<0.05$

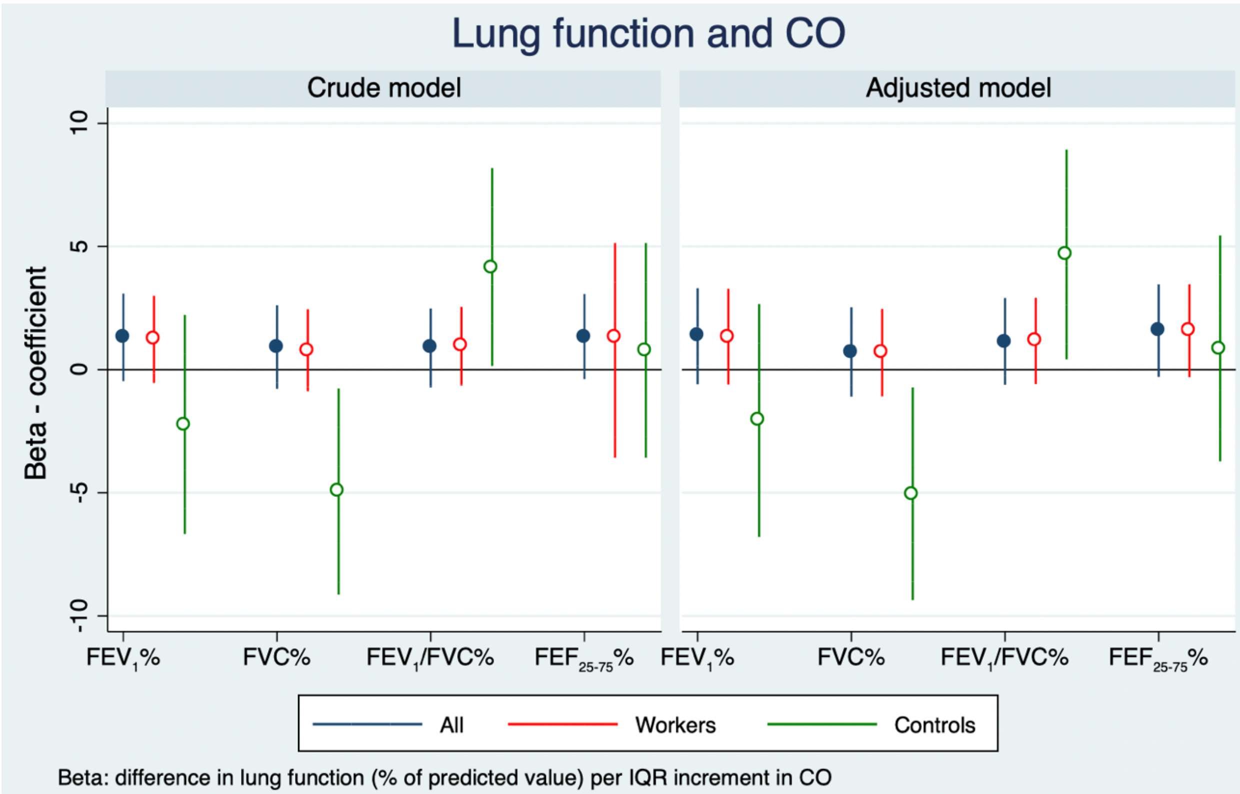


Figure 21B: Difference in lung function (% of the predicted value) per IQR increment in CO

As for the associations between three types of pulmonary function abnormality and its severity, overall, little evidence suggests the possible associations with minute-average $PM_{2.5}$ exposure. When I look at only point estimates of OR, there is a suggestive risk of Mixed pattern of pulmonary function abnormality for those who are exposed to higher $PM_{2.5}$ after adjusting for other risk factors: OR 1.20 (95%CI: 0.78, 1.85), 1.21 (0.79, 1.86) and 1.05 (0.43, 2.57) per IQR in $PM_{2.5}$ (52.04 µg/m^3) for all, workers and comparisons group, respectively (Table 21A).

Table 21A: Risk of pulmonary function abnormality per IQR increment in $PM_{2.5}$

$PM_{2.5}$				
	Crude OR[1] (95%CI)	***p-value for test of equality in group β***	**Adjusted OR[1) 2)] (95%CI)**	***p-value for test of equality in group β***
Types of pulmonary function abnormality				
Obstructive defect				
All (n=31)	1.06 (0.81, 1.40)	-	1.14 (0.83, 1.57)	-
Workers (n=16)	1.06 (0.81, 1.40)	0.5543	1.15 (0.84, 1.58)	0.3938
Comparisons (n=15)	0.86 (0.40, 1.86)		0.80 (0.33, 1.96)	
Restrictive pattern				
All (n=82)	0.77 (0.58, 1.03)	-	0.82 (0.60, 1.12)	-
Workers (n=31)	0.75 (0.55, 1.02)	0.0762	0.79 (0.56, 1.10)	0.1081
Comparisons (n=51)	1.15 (0.68, 1.95)		1.23 (0.68, 2.22)	
Mixed pattern				
All-participants	1.04 (0.74, 1.47)	-	1.20 (0.78, 1.85)	-
Workers (n=9)	1.04 (0.74, 1.47)	0.9671	1.21 (0.79, 1.86)	0.7325
Comparisons (n=10)	1.06 (0.47, 2.37)		1.05 (0.43, 2.57)	
Severity of pulmonary function abnormality				
Severe to Very severe				
All (n=46)	0.96 (0.52, 1.74)	-	0.97 (0.70, 1.34)	-
Workers (n=22)	0.96 (0.72, 1.26)	0.9821	0.98 (0.71, 1.35)	0.6134
Comparisons (n=24)	0.95 (0.52, 1.74)		0.83 (0.42, 1.65)	

[1)] Odds Ratios (ORs) of each outcome per IQR 52.04 $\mu g/m^3$ for $PM_{2.5}$.

[2)] adjusted for gender, marital status, number of years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

*p-value for test of equality in group β, $p<0.05$

Similarly, Table 21B suggests little evidence of increased risk of three types of pulmonary function abnormality and its severity due to CO exposure, except Restrictive pattern of pulmonary function abnormality for the control group: OR 2.74 (95%CI: 1.29, 5.83) per IQR increment in CO (1.76 ppb) (Table 21B). Workers group do not show such increased risk of Restrictive pattern of pulmonary function abnormality due to CO: OR 1.02 (95%CI: 0.82, 1.27) per IQR increment in CO.

Table 21B: Risk of pulmonary function abnormality per IQR increment in CO

CO				
	Crude OR[1] (95%CI)	***p-value for test of equality in group β***	**Adjusted OR[1) 2)] (95%CI)**	***p-value for test of equality in group β***
Types of pulmonary function abnormality				
Obstructive defect				
All (n=31)	0.89 (0.67, 1.67)	-	0.85 (0.63, 1.15)	-
Workers (n=16)	0.86 (0.64, 1.14)	0.2350	0.81 (0.59, 1.11)	0.1357
Comparisons (n=15)	0.54 (0.22, 0.30)		0.42 (0.16, 1.13)	
Restrictive pattern				
All (n=82)	0.95 (0.80, 1.13)	-	0.97 (0.80, 1.18)	-
Workers (n=31)	1.00 (0.82, 1.21)	0.0037*	1.02 (0.82, 1.27)	0.0034*
Comparisons (n=51)	2.27 (1.20, 4.30)		2.74 (1.29, 5.83)	
Mixed pattern				
All (n=19)	0.85 (0.59, 1.23)	-	0.80 (0.54, 1.18)	-
Workers (n=9)	0.80 (0.55, 1.17)	0.1468	0.75 (0.51, 1.12)	0.1370
Comparisons (n=10)	0.38 (0.12, 1.21)		0.33 (0.09, 1.13)	
Severity of pulmonary function abnormality				
Severe to Very severe				
All (n=46)	0.99 (0.81, 1.21)	-	0.98 (0.79, 1.22)	-
Workers (n=22)	0.99 (0.81, 1.21)	0.4954	0.98 (0.79, 1.21)	0.6348
Comparisons (n=24)	1.14 (0.72, 1.81)		1.09 (0.68, 1.76)	

[1)] Odds Ratios (ORs) of each outcome per IQR 1.76 ppb for CO.

[2)] adjusted for gender, marital status, number of. years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use.

*p-value for test of equality in group β, p<0.05

CHAPTER 5: DISCUSSION

5.1 Summary of key findings

This study aimed, for the first time, to quantify the levels of exposure to $PM_{2.5}$ and CO air pollution among workers performing cookstove activities in the gari industry (cassava grits processors) in the Bono East region of Ghana, and to investigate associations between these exposures and respiratory health among the workers compared to community comparisons. Most previous air pollution studies in similar settings have focused only on ambient and/or household air pollution, ignoring the importance of occupational exposures. The study adds to and strengthens the limited evidence on occupational air pollution in the gari industry.

Personal $PM_{2.5}$ and CO exposure monitoring profiles of workers over 48-hours revealed extremely high exposure levels (mean hourly-average 94.64 μg/m^3 (workers) and 41.27 μg/m^3 (comparisons) for $PM_{2.5}$ and 4.50 ppm (workers) and 1.94 ppm (comparisons) for CO), in particular during gari frying hours, but also during active home hours (including home cooking and burning activities) and non-active home hours (quiet home hours). Exposure levels in the gari workers were generally considerably higher than in the comparison group, in particular during daytime working hours. Cumulative exposure over the 48-hour monitoring period was higher in the workers (625 μg/m3 and 17.7 ppm) than the comparisons (259 μg/m3 and 12.8 ppm) for both $PM_{2.5}$ and CO. Occupational exposure during gari processing contributed more than a quarter of the total exposure among the workers for $PM_{2.5}$ and 80% for CO.

The analysis of associations between personal exposure to $PM_{2.5}$ or CO and lung function suggested little evidence of associations between IQR change in $PM_{2.5}$ or CO exposure and change in lung function parameters. There was evidence suggesting $PM_{2.5}$ and CO exposure may affect detrimentally some lung functions among the comparison group, but not for the worker group. However, this was not the case in the assessment of self-reported respiratory symptoms. The comparison group appeared to be generally healthier than the worker group, with workers roughly twice as likely to report having respiratory systems. Overall, there was little evidence of observable associations between air pollution exposure ($PM_{2.5}$ or CO) and respiratory health in terms of lung function parameters among this study participants in the Bono East region of Ghana.

5.2. Interpretation of results

(1) Exposure

This study found that gari workers were exposed to higher median $PM_{2.5}$ concentrations compared to the comparison group, in particular during the eight hours on average of cooking at the work sites. High exposure was also observed during active home hours for workers compared to home cooking hours in comparisons. $PM_{2.5}$ levels in both groups and in both the Kintampo South and Techiman North districts over the 48-hour personal exposure monitoring period far exceeded the 2005 WHO interim-I guidelines of 25 µg/m^3 (24-hour) and 10 µg/m^3 (48-hour) for $PM_{2.5}$ used in the past decade, and the recently updated 2021 WHO interim-I guidelines of 15 µg/m^3 (24-hour) and 5 µg/m^3 (48-hour). For CO levels, only the worker group in Kintampo South district (10.40 ppm) exceeded the 2005 WHO interim-I guidelines of 7 µg/m^3 (6.11 ppm) over a 24-hour personal exposure monitoring period [32, 131]. Although higher in the worker group, high $PM_{2.5}$ concentrations were also observed in the comparison group who used mostly biomass cookstoves at home as opposed to 'cleaner' stoves. Mean hourly-average $PM_{2.5}$ in workers during the day was twice as high (168 µg/m^3) as that of the comparison group (81 µg/m^3) and more than three times higher in workers (14.1 ppm) than the comparison group (3.3 ppm) for CO. Over the entire 48-hour monitoring period, cumulative exposure was higher in the workers (625 µg/m^3 and 17.7 ppm) than the comparisons (259 µg/m^3 and 12.8 ppm) for $PM_{2.5}$ and CO. Interestingly, median $PM_{2.5}$ and CO concentrations in both workers and comparisons were also reasonably high during quiet home hours (mean hourly-average 107.72 µg/m^3 (workers) and 40.72 µg/m^3 (comparisons) for $PM_{2.5}$ and 4.07 ppm (workers) and 1.93 ppm (comparisons) for CO). The study communities are also known for waste burning and mosquito coil and repellant use in their households, which may have resulted in the high exposure levels observed here during quiet home hours outside the occupational setting.

(2) Lung function parameters and assessment of pulmonary function

The objective analysis of lung function parameters between the two groups, suggested better respiratory health in the workers compared to the comparisons, although the results were mixed among types of lung function parameters after adjusting for gender, marital status, years in district, number of household persons, home cooking stoves, ventilation of cooking area, home cooking hours, occupation, BMI, education, passive smoking, trash burning, and mosquito coil use. Based on spirometry tests, the worker group had stronger lung function in terms of FEV_1 (mean+/-SD 1.60 ± 0.06) compared to the comparison group [(mean+/-SD 1.46 ± 0.4) t-test =-1.97 and p=0.050] and FVC (mean+/-SD 2.25 ± 0.63) compared to the comparison group [(mean+/-SD 2.04 ± 056 t-test =-2.44 and p=0.016]. The analysis found a significant difference in the prevalence of the restrictive lung function pattern between the worker and comparison groups, and this remained significant in the adjusted model. The restrictive pattern abnormality in the comparison group was almost twice that of the worker group. No significant difference was found for obstructive and mixed pattern lung function abnormality with the prevalence among workers (16.49% and 9.28%) and comparisons (15.46% and 10.31%) being comparable.

(3) Prevalence of self-reported respiratory symptoms

Unlike lung function parameters, analysis of self-reported respiratory symptoms through questionnaires revealed that workers had a higher prevalence of self-reported respiratory symptoms (cough, phlegm, and shortness of breath) compared to comparisons [2.24 (95%CI: 0.96, 5.24), although not significant. Little difference was observed in the prevalence in subjective respiratory symptoms between the two groups, although cough was more commonly reported by the worker group (22.7%) than the comparison group (16.5%). However, after adjusting for gender, marital status, years in district, number of household occupants, home cooking stoves, ventilation of cooking area, home cooking hours, BMI, education, passive smoking, trash burning, and mosquito coil use, doing 3 hours of home cooking [5.06 (95%CI: 1.37, 18.64)], BMI [6.70 (95%CI: 1.81, 24.87) (30kg/m^2 and above Obesity)], and coal pot use [0.23 (95%CI: 0.06, 0.90)] led to a significant difference in the prevalence of study participants developing any of the respiratory symptoms (with the worker group being more likely).

(4) Associations between air pollution exposure and lung function

This study found little evidence of an association between personal exposure to $PM_{2.5}$ or CO and lung function parameters. For some lung functions parameters, the associations were similar between the workers and the comparison group, except FVC%. There was a significant difference in FVC% between workers and comparisons, an IQR change in minute-mean $PM_{2.5}$ exposure level resulted in 1.53% (-0.88%, 3.94%) in workers vs -3.88% (-9.12%, 1.36%) difference in comparisons and 0.69% (-1.08%, 2.46%) in workers and -5.04% (-9.36%, -0.73%) in comparisons for CO. The negative point estimates suggest possible detrimental impacts on FVC% in the comparison group. The measure of FEV_1/FVC%, suggested weak evidence of the association with $PM_{2.5}$ [-1.07% (-3.46%, 1.32%) in workers compared to [-0.34% (-5.53%, 4.85%) per IQR change] in the comparison group. Whereas FEV_1/FVC%, suggested little evidence CO [1.16% (-0.59%, 2.91%) in workers compared to [4.68% (0.42%, 8.94%) per IQR change] in the comparison group.

There are several possible explanations for the mixed observations across different measures of lung health and the lack of association with air pollution exposure. Perhaps most importantly, it was not possible to control rigorously for the effects of biomass exposure outside the occupational setting (e.g. at active home hours and quiet home hours). From reviewing time plots of participants' exposures, workers commonly had high exposure during quiet home hours that for some participants fell in gari frying hours. The comparison group regularly used biomass fuel for home cooking, whereas the worker group more commonly reported not cooking every day at home due to the early morning start at the processing sites, the intensity of the work and the duration of hours spent standing by the gari processing cookstoves in the day. Due to the early start of work at the gari processing sites, workers often cooked breakfast at the gari processing sites using the same stoves as were used for processing. This was witnessed first-hand by the research team at processing sites as workers were observed to use small traditional aluminium cooking pots to prepare their breakfast on the large surface pans for processing casava grits.

5.3. Comparison with other studies

Previous occupational studies of industries involving cooking with biomass conducted in Nigeria (see literature review in chapter 2) have assessed prevalence of self-reported respiratory symptoms such as cough, phlegm, chest pain, shortness of breath and emphysema for workers exposed to biomass-related air pollutants compared to non-biomass exposed controls [76, 87]. This study observed little differences in the prevalence of respiratory symptoms (cough, phlegm, and shortness of breath) in the worker group compared to the comparison group, which did not agree with large differences found in studies by Okwor et al. (2017), Adewole et al. (2013) and Dienye et al. (2016) who examined respiratory symptoms and lung function in gari workers, meat grilling and fish smoking workers in Nigeria [75, 76, 87]. Dienye et al. (2016) found positive associations with cough and phlegm in fish smokers in Nigeria from the use of biomass fuel cookstoves, which is broadly similar to this study [75]. In this study, following the adjusted model, hours of home cooking, cooking with coal pot, elevated BMI increased workers prevalence of developing cough compared to comparisons, but no obvious difference was found in the frequency of obstructive defect in workers as Okwor et al. (2017) concluded [87]. On the other hand, Okwor et al. (2017) [87] found lower pulmonary function parameters in the worker group, whereas this study found a significant effect on restrictive pattern in comparisons compared to workers.

An increased prevalence of respiratory symptoms among biomass food vendors in Brunei was observed in Nazurah Bt Abdul Wahid et al. (2014) and in restaurant kitchen frying cooks in Thailand by Juntarawijit and Juntarawijit (2017), especially with increased duration of years in industry and duration of working hours, although that study had a different comparison group that showed an increased prevalence of developing cough in workers compared to comparisons with increase in home cooking hours [132, 133]. In comparison to 8.8% of cough in charcoal workers in Nigeria reported by Obiebi and Oyibo (2019), workers in this gari study reported an increased prevalence of cough after the adjusted model [56]. When shortness of breath was assessed, only 2% of grits workers had an increased occurrence compared to 19.6% of charcoal workers [53].

This study's findings of FEV_1% predicted and FVC% predicted being higher in the worker group compared to the comparison group are incongruent with those of gari workers and meat grillers in Nigeria by Okwor et al. (2017) and Adewole et al. (2013) who found the reverse [76, 87].This may be because they used aerial rather than personal monitoring. The mean FEV_1 of 1.60 ± 0.06L, and the mean FVC of 2.25 ± 0.63L recorded in this study are comparable to levels found in gari workers (1.58 ± 0.38L and 2.11 ± 0.37L) and charcoal workers (1.56 ± 0.54L and 1.95 ± 0.70L) in the studies conducted by Okwor et al. (2017) and Obiebi et al. (2017) in Nigeria [87, 134]. However, this study reported much lower means of FEV_1 and FVC in its worker group compared to an exposure study among gari workers (2.00 ± 0.76L and 2.55 ± 1.07L) and on biomass street cooks in Nigeria (1.93 ± 0.49L and 2.43 ± 0.55L) by Oloyede et al. (2018) and Awopeju et al. (2017) [58, 135]. This study found the mean FEV_1/FVC% was 71% in the worker group and 72% in the comparison group compared to the Okwor et al. (2017) study [84]. On the contrary, the Obiebi et al. (2017) study of charcoal workers in Nigeria reported higher FEV_1/FVC of 98.96% in the worker group and 90.30% in the comparison group [123].

This study found slightly lower FEV_1/FVC in workers compared to comparisons, similar to studies conducted in Nigeria in gari workers and in fish smokers that obstructive defects were more common lung function abnormalities (followed by restrictive patterns) in workers [84, 90]. However, the findings of obstructive defects in this study were not significant and consistent with studies in Nigeria by Obiebi et al. (2017) in charcoal workers and Oloyede et al. (2018) in gari workers that found restrictive patterns to be predominant in workers followed by obstruct defects and mixed patterns, although the latter two results were non-significant [58, 134]. Rates of obstructive defects in my study were non-significantly higher in the worker group than the comparison group, unlike in Oloyede et al. (2018), which assessed only spirometry and found a significant association between respiratory symptoms and restrictive, obstructive, and mixed pattern abnormalities in its worker group [58]; this thesis study assessed both personal exposure and spirometry. This study found restrictive patterns to be predominant in comparisons compared to workers.

A study in southern Ghana by Fosu-Mensah et al. (2021) found workers who work for an average of eight hours daily and increased years of experience at the gari processing site have higher risk of inhaling pollutants compared non-workers, especially if workers do not wear any personal protective equipment [89]. Average-minute $PM_{2.5}$ concentrations in this thesis study were higher than those in Okwor et al. (2017)

conducted in gari workers in Nigeria that measured 50 ± 10μg/m^3 in workers versus 13 ± 10μg/m^3 in controls [84]. This finding reveals the magnitude of occupational exposure hazard from the gari industry, and is consistent with reports from Nigeria, Thailand, and Brunei [55, 121, 122].

Workers' generally low educational levels may have limited their knowledge on adverse health effects from exposure to biomass fuel, consistent with findings reported by Nwankwo et al. (2018) in food vendors in Nigeria [74]. Although Umoh et al. (2013) found fish smoking workers in Nigeria, compared to non-biomass exposed comparisons, had higher educational levels on average, this was not reflected in their knowledge on the adverse health effects of air pollution exposure [90]. On the contrary, Umoh et al. (2013) concluded the education that workers obtained in rural settings may have not been optimal [90]. Nwankwo et al. (2018) found that access to higher education increased awareness on the adverse health effects of biomass smoke in food vendors, which is consistent with some previous studies in this area [71, 134-136]. Various studies have more generally confirmed the association of educational level and the use or adoption of clean cooking energy [137, 138].

About 50% of workers in this study had no formal educational training compared to the comparison group, and this percentage of workers was higher than previously conducted studies in the gari processing industry or similar occupational industries. Oloyede et al. (2018) also found that gari workers in Nigeria had lower formal educational training compared to non-biomass occupational workers [55]. However, the comparison group in this study and similar studies conducted in Nigeria by Oloyede et al. (2018), Okwor et at. (2017), and Umoh et al. (2013) involving gari workers and fish smokers had attained higher educational training at the middle junior high and post-secondary level [55, 84, 90].

The workers in this study were generally quite young and air pollution-related health effects increase greatly with increasing age – the ages of participants were between 20 and 59 years, with less than 5% of the study population over 50 years of age [99]. There were also some differences in the characteristics of the two groups in the study. A high percentage of the gari workers were females and the comparison group were made up of seamstresses, traders and farmers. This may be indicative of society's expectations of women being responsible for cooking, food handling, and occupations deemed feminine in Ghana [139]. There were also more married than single participants in the worker group compared to the comparison group, and participants in the worker group generally used open mokyia stoves (3-stone, mud or clay stove) more than closed mokyia stoves (metal/clay), coal pot or gas stove for home cooking. More than 50% of workers in the study had no formal educational training and the highest educational level was at the primary level in

34% of workers. As a result, the worker group may be less aware of the health risks of occupational air pollution exposure than comparisons.

5.4. Strengths and limitations of the research

(1) Strengths

A major strength of this study was improving on previous studies that used area measures of air pollution. This study performed simultaneous assessment of personal exposure to both $PM_{2.5}$ and CO, using two portable devices - Lascar for CO and PATS+ devices for $PM_{2.5}$ - taken over a 48-hour period rather than relying on proxies for exposure such as fuel use or self-reported years of exposure. The use of these portable personal exposure monitoring devices enabled detailed time-varying characterisation of 48-hour exposure profiles to both $PM_{2.5}$ and CO and understanding of the temporal fluctuations of personal exposure to $PM_{2.5}$ and CO at gari frying hours and active hours in worker group, home cooking hours in comparison group and quiet hours in both groups, linking exposure levels to the time of the day. The devices are viable methods for understanding individual level exposures compared to ambient levels [85]. Both of the devices are lightweight and able to capture real-time exposure measurements for up to 72-hours, ranging from 10 $\mu g/m^3$ to 50,000 $\mu g/m^3$ for $PM_{2.5}$ and from 3 ppm to 1000 ppm for CO. Another strength of this study was in assessing the relationship between personal exposure and lung function, using objective and robust measures of respiratory health obtained using spirometry, complemented by self-reported measures of respiratory symptoms among workers compared to the comparison group.

Through careful selection and matching of comparisons to workers, this study also performed matching exposure monitoring in comparisons and workers from closely related age groups, households and communities within a one-week time span to limit the effects of weather variations. The work also used a robust method to study a representative_sample of gari processing sites in Ghana from two districts, the Kintampo South district and Techiman North district in the Bono East region of Ghana that produces the largest amount of gari in the country. Importantly, this study also focused on an under-studied population group and setting (including a large proportion of women who may be more vulnerable to biomass exposure).

(2) Limitations

Among the key limitations of the work, it was not possible to acquire ambient monitoring of $PM_{2.5}$ and CO to help interpret the personal monitoring data in the context of local air pollution levels. Second, the self-reported data on respiratory symptoms from questionnaires posed to participants meant that responses were not validated and may have been prone to recall bias. Also, the symptoms were translated from English to Twi (the local language) and described to participants by field workers so inaccuracy of translation or description of symptoms may have introduced bias and affected participants' responses. Moreover, in translating or describing the symptoms, field workers may have used different words for the same symptoms which may have led to sampling bias. However, this may not have affected the findings greatly since spirometry manoeuvres were also performed on each participant to obtain more objective data on participants' lung function capacity. Third, this study failed to identify traffic pollution sources which may have been a confounding variable because the gari processing sites were commonly close to roadways, and some households were near major roads. Fourth, this study was conducted in only two specific districts in the Bono East region of Ghana and focused on workers engaged in gari processing cookstove activities, so the findings may not be generalizable to workers engaged in other stages in the gari processing industry and in particular may not be directly applicable to other countries.

Fifth, the one-time measurement of $PM_{2.5}$ or CO may not have adequately quantified the long-term effects of exposure on lung function, as day-to-day exposures at the gari processing sites may have varied. Although, this study tried to minimize this variation by performing exposure measurements in both study groups within the same time and day period, more measurements at different times in different seasons may help to better characterize the exposures. Sixth, this study was a cross-sectional design but may have benefitted from a longitudinal design because associations between exposure and respiratory symptoms or lung function abnormalities may not be causal. Finally, additionally, this study did not have information on cooking at home for the worker group. An assumption was made about the gari workers' cooking time at home based on subjective measures of the time gari workers started the fire at the cookstove at their individual workstations in the gari processing sites and the time workers put out the fire. In controls, this information was retrieved for home cooking. Thus, biomass combustion-related exposure at the work site and at home was not properly controlled in either group.

5.5. Implications of the research

The findings of this study suggest some implications for future research and policy to reduce occupational biomass air pollution exposure and its health effects. Although this study observed little evidence of an association between $PM_{2.5}$ or CO exposure and respiratory health, exposures were considerably higher in the worker group, suggesting that it may be beneficial for the Ghanaian government to institute similar measures in occupational settings to current rural LPG initiative introduced to curb the household air pollution in Ghana by increasing access to clean cookstoves, perhaps through subsidies on clean cookstoves [140]. The Ministry of Health/Ghana Health Service has an LPG initiative that was formed to replace biomass cookstoves in the country, and it is estimated that over 90% of households have a preference for these cookstoves [141]. Similar measures aimed at the improvement of current cookstoves in the gari processing industry could be implemented by promoting clean fuels such as the provision of electrical frying machines or LPG stoves as a preventive measure to the likely adverse health effects from prolonged biomass cookstove use. However, there are significant costs to accessing these clean cooking cookstoves which may act as a barrier to uptake.

It may be feasible for the Ghanaian government to learn from the Gyapa Enterprise cookstove program in Ghana that worked with communities and international organizations such as Relief International and ClimateCare to develop and implement fuel-efficient charcoal cookstoves as an alternative for traditional biomass cookstoves [142, 143]. The gari processing industry in Ghana generally uses specially constructed wood-fuel cookstoves which increases deforestation. It is essential for the Ghanaian government to work with workers in the gari processing industry and surrounding communities near processing sites to better understand why the industry uses this type of cookstoves and how to develop and produce fuel-efficient cookstoves for the industry.

The limited previous studies from the food processing industries that use biomass fuel cookstoves in the African region make it difficult for the populace to be aware of the adverse effects from these cookstoves. With less than 35% of workers in this study (and similarly in other studies) obtaining post-secondary education, awareness on the adverse health effects of biomass exposure is likely to be poor and will need to be addressed in workers of food processing industries [84,89]. The Ghanaian government could consider creating educational programs that focus on improving awareness of the health impacts of biomass-related air pollution in the food processing industries to help mitigate the harmful effects of prolonged biomass use.

5.5.1 Recommendations for future research

To improve understanding on air pollution exposures and health effects in occupational settings like the one in this study, further studies are needed to assess air pollution exposures in the wider community, at home and gari processing work sites because study participants may also have been exposed to air pollution from other sources, such as dust and fumes from transport vehicles, while at the gari processing sites (which are mostly situated by roadsides) or, for comparisons, while performing their occupational duties (mostly farming and trading) or at home. In particular, studies should collect detailed time-activity and cooking data to help control for the effects of HAP. There is also a need for intervention studies to assess the impact of measures to reduce exposure (such as switching to cleaner stoves) in the gari processing industry.

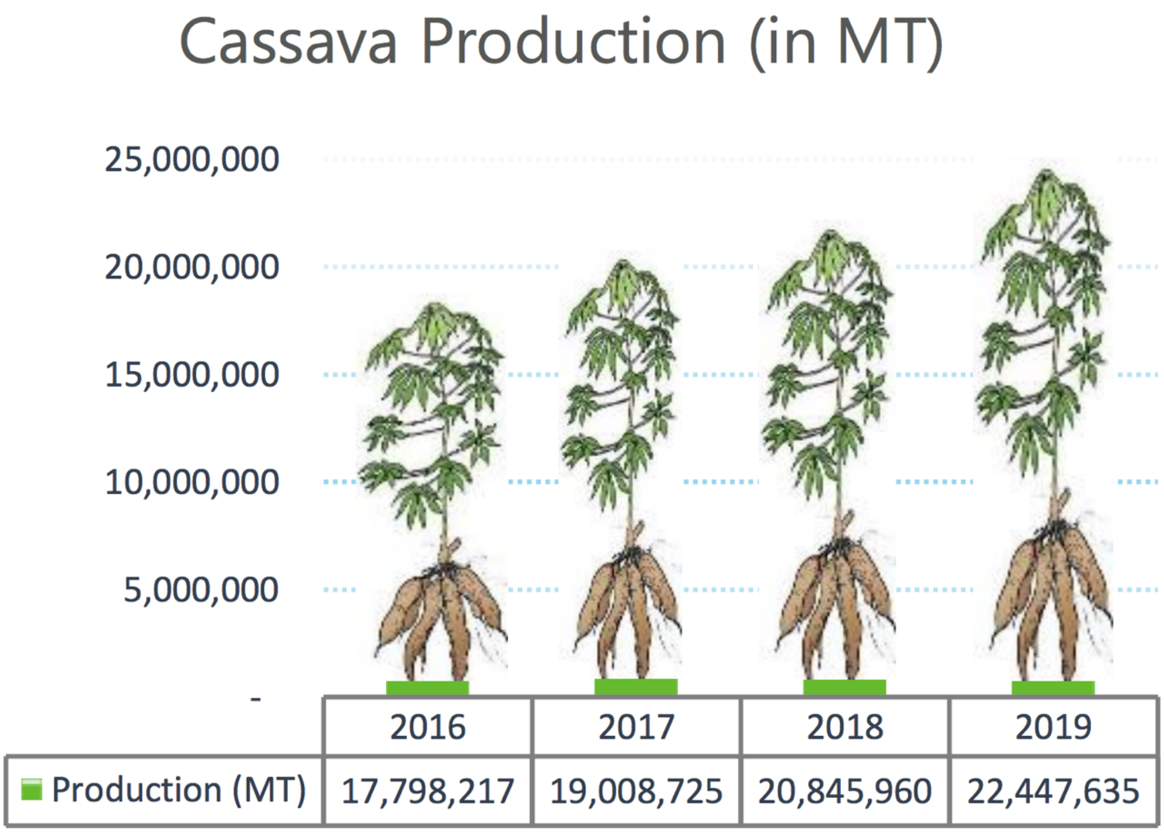
However, this will require better understanding of the motivations behind people's use of biomass cookstove in this industry, behaviour changes through increased awareness of the benefits of clean cooking energy, household socioeconomic status and policy changes targeted at reducing emissions.

CHAPTER 6: CONCLUSION

To my knowledge, this is the first study in Ghana to assess lung function in relation to both occupational $PM_{2.5}$ and CO exposure in this population of workers in the gari processing industry. Using 48-hour personal monitoring, this study found elevated levels of $PM_{2.5}$ exposure above the 2005 and 2021 WHO interim-I guidelines of 10 μg/m^3 and 5 μg/m^3 (48-hour), and above the 2005 WHO interim-I guideline of 7 μg/m^3 for CO. In general, exposures to both $PM_{2.5}$ and CO were considerably higher in the worker group than in community comparisons. Despite this, there was limited evidence that exposure to occupational air pollution in the gari processing industry was associated with poor respirator health or lung functional abnormalities. However, workers had a higher prevalence of respiratory symptoms (cough, phlegm, shortness of breath) than the comparison group and lung function tests suggested possible detrimental impacts on some lung function parameters in the comparison group. It is important for the Ghanaian government to prioritise changing fuel type for gari processing given the high exposure.

APPENDICES

Appendix A: 2016 – 2019 Cassava Production in million metric tonnes



Source: GHANA EXPORT PROMOTION AUTHORITY (GEPA) [144]

Appendix B: Sample Size Calculation

Stata command: sampsi 0.064 0.219, alpha (.05) power (.8) ratio (1)

alpha = 0.0500 (two-sided)

power = 0.8000

p1 = 0.064

p2 = 0.219

n2/n1 = 1.00

Estimated required sample sizes:

n1 = 91

n2 = 91

91 X 2= 182

182 X 0.07 (we are assuming 7% loss to follow-up) = 12.74

12 +182 = 194

Appendix C: Participant Information Sheet

PARTICIPANT INFORMATION SHEET

Study title: Exposure to air pollution and lung function among cassava grits processors in the Bono East region of Ghana
Investigator Name and Contact: Omolola Adeshina; Omolola.adeshina@lshtm.ac.uk or 0549499332

Introduction
I would like to invite you to take part in a study on "Exposure to air pollution and lung function among cassava grits processors in Ghana". You have the choice of joining the study or not joining it. Before you decide, you need to understand the purpose and aim of the study, including what will be required of you to take part. I will go through this information sheet with you and answer any questions you may have or that I have not properly explained. Please feel free to share about the study with others if you wish.

Purpose of the study
Smoke from the cook stove used to fry gari emits smoke that is harmful to an individual's health with prolonged exposure. The smoke emitted from the cook stoves has been linked to diseases such as obstructive airways disease, chronic obstructive pulmonary disease, loss of pregnancy, and increased infant mortality rates.

Study aim
You have been invited because I want to measure the amount of smoke [carbon monoxide (CO) and fine particulate matters ($PM_{2.5}$, particles with a diameter less than 2.5 micrometres, μm)] that you are exposed to while frying gari on the cookstove you work with. I want to take these measurements to associate the levels of smoke the cook stove from the gari industry emits to respiratory symptoms and lung function. I would also like to compare these levels to another group that is not in the gari industry so if you are not in the gari industry, I want to also measure if at all you may be exposed to any smoke (CO and $PM_{2.5}$) in your community during the day and at night. If you have any questions about the study, I will answer them.

Your participation
It is up to you whether you decide to participate or not in the study. If you decide to take part, I and the translator will discuss other aspects of the study together and give you a copy of this information sheet, and also go through the consent form if you agree to take part. Participation is confidential, and participants may choose to withdraw from this study without giving a reason. If you decide to withdraw, we need to use the data collected on you up to your withdrawal.

Once you have agreed to take part, I will demonstrate how I will be using the devices to measure the amount of smoke. All you have to do is have the two stated devices on you for a 48-hour period. The CO device is a small device that looks like the size of a marker. I will clip the CO device onto your clothing and the $PM_{2.5}$ will be in a small bag like a fanny pack that you will have to wear across your chest.

Risks and disadvantages
No harm is expected in the course of this study to you. You will however be asked some questions that might sound personal to you. You will not be forced to respond to all questions, and you are free to stop the interview if you feel uncomfortable. Some participants may feel inconvenienced in stopping work briefly for investigator to collect measurements.

You may experience some discomfort in having the measuring device clipped on the top of clothing or worn in bags across their upper chest area. The carbon monoxide (CO) device has a slim cylindrical marker-like frame weighing 0.16kg, with a length of 12.5cm and a height of 2.62cm. The particulate matter ($PM_{2.5}$) device has a cube-like frame weighing 4 ounces, with a height 13cm, length of 7.2cm and width of 3.3cm. Due to the size of the CO being like a marker and the $PM_{2.5}$ placed in fanny packs similar to money waist belts participants sometimes wear, there have not been any reported interference with participants' normal movement from household air pollution studies conducted using these two devices in the same region as the proposed study.

Benefits
You will not personally benefit directly from this study. The information and measurements we get from you, will help us know smoke levels that lead to respiratory symptoms and that can eventually affect lung function of study participants as yourself, fellow co-workers, or individuals in a similar working environment.

How confidentiality will be ensured
Privacy and confidentiality of participants' information will be ensured by storing processor assigned study ID like GM0001G, GM0009G. Participants' identifiers (names) will not be used when storing data. Files and data will be kept for eight years after study.

Dissemination of Results
The final report will be submitted to the LSHTM for grading and the investigator intends to develop and publish manuscripts from study outcome measures. Your personal information will be excluded from published manuscripts so you cannot be identified.

Funding
Partial sponsorship for the research has been received from London School of Hygiene & Tropical Medicine and I will be self-funding the remainder of the research. All required equipment is already in place. I have full responsibility for the project including the collection, storage and analysis of your data.

Ethical approval
The study has been approved by the London School of Hygiene and Tropical Medicine's Ethics Committee, the Kintampo Health Research Centre Scientific Review Committee and the Kintampo Health Research Centre Institutional Ethics Committee.

Further information and contact details
Thank you for taking time to read this information sheet. If you have any further questions or queries about the study, please do not hesitate to contact me at omolola.adeshina@lshtm.ac.uk or 0549499332.

If you have any further questions or queries about the conduct of the research study please do not hesitate to contact the London School of Hygiene and Tropical Medicine at ethics@lshtm.ac.uk

Appendix D: Informed Consent Form

London School of Hygiene & Tropical Medicine

TITLE OF RESEARCH PROJECT:	Exposure to air pollution and lung function among cassava grits processors in the Bono East region of Ghana
INFORMED CONSENT FORM for (Type of Participants)	Grits fryers (workers perform cookstove activity) and non-grits fryers

PURPOSE OF STUDY/BACKGROUND
Smoke from the cook stove used to fry gari emits smoke that is harmful to an individual's health with prolonged exposure. The smoke emitted from the cook stoves has been linked to diseases such as obstructive airways disease, chronic obstructive pulmonary disease, loss of pregnancy, and increased infant mortality rates. I want to measure the amount of smoke [carbon monoxide (CO) and fine particulate matters ($PM_{2.5}$, particles with a diameter less than 2.5 micrometres, µm)] that you are exposed to while frying gari on the cookstove you work with. I want to take these measurements to associate the levels of smoke the cook stove from the gari industry emits to respiratory symptoms and lung function. I would also like to compare these levels to another group that is not in the gari industry so if you are not in the gari industry, I want to also measure if at all you may be exposed to any smoke (CO and $PM_{2.5}$) in your community during the day and at night. If you have any questions about the study, I will answer them.

PROCEDURES
I will be measuring smoke levels with two devices named, lascar and PATs+ device. If you agree to be part of the study, you will need to have two of the smoke measuring device on you for 48-hours (2-days), one of the device will be clipped onto the top of your clothing and the second will be put in a small bag for them to wear across your chest. For all measurements, I will require 48-hours 30minutes of your time to participate in this study. The 30 minutes will be to fill the enrolment form on day 1 if you decide to take in the study.

RISKS/DISCOMFORTS
No harm is expected in the course of this study to you. You will however be asked some questions that might sound personal to you. You will not be forced to respond to all questions, and you are free to stop the interview if you feel uncomfortable.

BENEFITS
You will not personally benefit directly from this study. The information and measurements we get from you, will help us know smoke levels that lead to respiratory symptoms and that can eventually affect lung function of study participants as yourself, fellow co-workers, or individuals in a similar working environment.

COMPENSATION
Key soap

CONFIDENTIALITY
I will ensure privacy and confidentiality of information by storing your assigned study ID like GM0001G, GM0009G. Your name will not be used when storing data, writing or talking about this study. There will be use of your anonymized data in the public domain via a data repository.

VOLUNTARINESS
Your participation in this study is voluntarily. You have the right to withdraw from the study and all measurements collected before withdrawing will be destroyed. You may withdraw at any time without any penalty. If you decline to participate or later stop participating, you will not be adversely affected.

Contact persons
If you want to ask concerning this study, you may contact me (Omolola Adeshina) on telephone number 0549499332 and, Livesy Abokyi, on telephone number 0244517979

Participants Rights; If you have any ethical concerns during or after your participation in this study, please contact the Administrator of the Kintampo Health Research Centre Institutional Ethics Committee on 0504270501.

Consent statement:
I have read the above study information, or it has been read to me. I have had the opportunity to ask questions about it and questions I have asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study. I also understand that the information collected will be treated confidentially and will be used only for the purpose informed. I will be given a copy of this informed consent form.

....
Name of Participant Signature or thumb print

Date ……/……/………

Witness (Witness to Consent Procedures if Participant cannot read)
A witness's signature and the participant's thumbprint are required only if the participant is illiterate. In this case, a literate witness must sit throughout the entire period of the consenting process, write his or her name, date and sign this document.
''I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely''.

....
Name of Witness Signature

Date ……/……/………

Investigator Consent
I certify that the nature and purpose, the potential benefits, and possible discomforts associated with participating in this research have been explained to the potential participant. I have answered all questions that have been raised and have witnessed the above signatures on the date indicated above.

Name: ……………………………….. Date: …..../……../………...

Signature: …………………………………...

Appendix E: Information Sheet - For parents/guardians of respondents less than 18 years

KINTAMPO HEALTH RESEARCH CENTRE/ LONDON SCHOOL OF HYGIENE & TROPICAL MEDICINE

EXPOSURE TO AIR POLLUTION AND LUNG FUNCTION AMONG CASSAVA GRITS PROCESSORS IN THE BONO EAST REGION OF GHANA

Information Sheet: For parents/guardians of respondents less than 18 years.

Introduction
My name is Omolola Adeshina, I am a student of the London School of Hygiene & Tropical Medicine. The Kintampo Health Research Centre and the London School of Hygiene & Tropical Medicine (LSHTM) are conducting research to measure the amount of smoke [carbon monoxide (CO) and fine particulate matters (PM2.5, particles with a diameter less than 2.5 micrometres, µm)] that individuals are exposed to while frying gari on the cookstove they work with.

Purpose: The KHRC/LSHTM study wants to compare exposure levels inhaled from the cook smoke of frying gari to another group that is not in the gari industry so if individuals are not in the gari industry, we want to also measure if at all they may be exposed to any smoke (CO and PM2.5) in their community during the day and at night.

Invitation: We invite your child to participate in this study because he/she is a minor and we feel that their exposure levels should not be ignored and is important in understanding more about this topic of interest.

Method: If you would like for your child to join this study, we will be measuring smoke levels with two devices named, lascar and PATs+ device, and a third device called a spirometer, to check respiratory airflow/obstruction/restriction of their lungs. If you agree for him/her to be part of the study, we will need to have two of the smoke measuring device on him/her for 48-hours (2-days), one of the device will be clipped onto the top of their clothing and the second will be put in a small bag for them to wear across their chest. For the third device, trained personnel will take measurements with your child on Day-1 and Day-2. The trained personnel will be taking their vital signs such as blood pressure, pulse, height, and hip and waist circumference. For all measurements, we will require 48-hours 30minutes of your child's time to participate in this study. The 30 minutes will be to fill the enrolment form on day 1 if you agree for your child to take in the study.

Risks and benefits:
No harm is expected in the course of this study to your child. He/she will however be asked some questions that might sound personal to them. Your child will not be forced to respond to all questions and is free to stop the interview if they feel uncomfortable. He/she may experience some discomfort in having to wear the personal exposure monitors for 48-hours. The measurement of hip circumference, blood pressure, pulse, height and weight may be intrusive. Your child will not personally benefit directly from this study. The information and measurements we get from them, will help us know smoke levels that lead to respiratory symptoms and that can eventually affect lung function of study participants as themselves, fellow co-workers, or individuals in a similar working environment.

Willingness to participate or withdraw: Your child's participation in this study is voluntarily. He/she has the right to withdraw from the study and all measurements collected before withdrawing will be destroyed. He/she may withdraw at any time without penalty. If you decline for your child to participate or later stop participating, he/she will not be adversely affected. This project has been reviewed by, and received ethics clearance through, the Kintampo Health Research Centre Institutional Ethics Committee, and the London School of Hygiene & Tropical Medicine.

Your child's involvement in this study is greatly appreciated. If you are happy for him/her to take part in the study, please read and sign the attached consent form.

If you have a concern about any aspect of this project, please write to Mrs. Livesy Abokyi at Kintampo Health Research Centre; Box 200, Kintampo or speak to her on telephone number 0244517979. She will do her best to answer your question. If you have any ethical concerns during or after about your child's right as a participant in this study, please contact the Administrator of the Kintampo Health Research Centre Institutional Ethics Committee on 0504270501.

Statement of consent: To be completed by participant

- I have read the above study information, or it has been read to me. I have had the opportunity to ask questions about it and questions I have asked have been answered to my satisfaction.
- I understand that this project has been reviewed by, and received ethics clearance through, Kintampo Health Research Centre Institutional Ethics Committee and the London School of Hygiene & Tropical Medicine.
- I understand that my child's participation is voluntary, and that he/she can withdraw their consent at any time without further explanation.
- I understand that this study involves measuring smoke levels with two devices, and a third device to check respiratory airflow/obstruction/restriction of their lungs.
- I understand that their data will be stored safely on password protected computers.
- I also understand that the information collected will be treated confidentially and will be used only for the purpose informed and will not be shared with people outside the research group.
- I understand that only group results, and not my individual results, will be available for scientific and public health purposes.
- I understand that my child will not personally benefit directly for being in the study.
- I understand how to raise concerns or make a complaint and I have been informed on whom to contact.
- I agree for my child to take part in the study.

Names of parent/guardian: ………………………………………………………..

Date (dd/mm/yyyy): …………/…………/20…………Signature:……………………………

Or Thumbprint

If illiterate, please get a witness.**

Witness statement
I have witnessed the accurate reading of the consent form to the participants' parent/guardian and the parent/guardian has had the opportunity to ask questions. I attest to the parents'/guardians' agreement for their child to voluntarily join the study by the appending of thumbprint or signature to signify consent by the parent/guardian.

Name of witness: ………………………………………………………..

Date (dd/mm/yyyy): …………/…………/20…………Signature:……………………………

To be completed by the Researcher/Representative

I certify that the nature and purpose, the potential benefits, and possible discomforts associated with participating in this research have been explained to the potential participant. I have answered all questions that have been raised and have witnessed the above signatures on the date indicated above.

Name of Researcher:…………………………………………………………………

Date (dd/mm/yyyy):………./………/20……………Signature:……………………..

Appendix F: Assent Form - Minor (For both grits fryers and controls)

KINTAMPO HEALTH RESEARCH CENTRE/ LONDON SCHOOL OF HYGIENE & TROPICAL MEDICINE

EXPOSURE TO AIR POLLUTION AND LUNG FUNCTION AMONG CASSAVA GRITS PROCESSORS IN THE BONO EAST REGION OF GHANA

ASSENT FORM: Minor (For both grits fryers and controls)

Introduction
My name is Omolola Adeshina, I am a student of the London School of Hygiene & Tropical Medicine. The Kintampo Health Research Centre and the London School of Hygiene & Tropical Medicine (LSHTM) are conducting research to measure the amount of smoke [carbon monoxide (CO) and fine particulate matters (PM2.5, particles with a diameter less than 2.5 micrometres, µm)] that you are exposed to while frying gari on the cookstove you work with.

Purpose: The KHRC/LSHTM study wants to compare exposure levels inhaled from the cook smoke of frying gari to another group that is not in the gari industry so if you are not in the gari industry, we want to also measure if at all you may be exposed to any smoke (CO and PM2.5) in your community during the day and at night.

Invitation: We invite you to participate in this study because you are an adolescent, and we feel that your exposure levels should not be ignored and is important in understanding more about this topic of interest.

Method: If you are interested in joining this study, we will be measuring smoke levels with two devices named, lascar and PATs+ device, and a third device called a spirometer, to check respiratory airflow/obstruction/restriction of your lungs. If you agree to be part of the study, you will need to have two of the smoke measuring device on you for 48-hours (2-days), one of the device will be clipped onto the top of your clothing and the second will be put in a small bag for you to wear across your chest. For the third device, trained personnel will take measurements with you on Day-1 and Day-2. The trained personnel will be taking your vital signs such as blood pressure, pulse, height, and hip and waist circumference. For all measurements, we will require 48-hours 30minutes of your time to participate in this study. The 30 minutes will be to fill the enrolment form on day 1 if you decide to take in the study.

Risks and benefits: No harm is expected in the course of this study to you. You will however be asked some questions that might sound personal to you. You will not be forced to respond to all questions, and you are free to stop the interview if you feel uncomfortable. You may experience some discomfort in having to wear the personal exposure monitors for 48-hours. The measurement of hip circumference, blood pressure, pulse, height and weight may be intrusive. You will not personally benefit directly from this study. The information and measurements we get from you, will help us know smoke levels that lead to respiratory symptoms and that can eventually affect lung function of study participants as yourself, fellow co-workers, or individuals in a similar working environment.

Willingness to participate or withdraw: Your participation in this study is voluntarily. You have the right to withdraw from the study and all measurements collected before withdrawing will be destroyed. You may withdraw at any time without penalty. If you decline to participate or later stop participating, you will not be adversely affected. This project has been reviewed by, and received ethics clearance through, the

Kintampo Health Research Centre Institutional Ethics Committee, and the London School of Hygiene & Tropical Medicine.

Your involvement in this study is greatly appreciated. If you are happy to take part in the study, please read and sign the attached consent form

If you have a concern about any aspect of this project, please write to Mrs. Livesy Abokyi at Kintampo Health Research Centre; Box 200, Kintampo or speak to her on telephone number 0244517979. She will do her best to answer your question. If you have any ethical concerns during or after your participation in this study, please contact the Administrator of the Kintampo Health Research Centre Institutional Ethics Committee on 0504270501.

Statement of Assent: To be completed by participant

- I have read the above study information, or it has been read to me. I have had the opportunity to ask questions about it and questions I have asked have been answered to my satisfaction.
- I understand that this project has been reviewed by, and received ethics clearance through, Kintampo Health Research Centre Institutional Ethics Committee and the London School of Hygiene & Tropical Medicine.
- I understand that my participation is voluntary, and that I can withdraw my consent at any time without further explanation.
- I understand that this study involves measuring smoke levels with two devices, and a third device to check respiratory airflow/obstruction/restriction of my lungs.
- I understand that my data will be stored safely on password protected computers.
- I also understand that the information collected will be treated confidentially and will be used only for the purpose informed and will not be shared with people outside the research group.
- I understand that only group results, and not my individual results, will be available for scientific and public health purposes.
- I understand that I will not personally benefit directly for being in the study.
- I understand how to raise concerns or make a complaint and I have been informed on whom to contact.
- I agree to take part in the study.

Name of participant: ………………………………………………………..

Date (dd/mm/yyyy): …………/…………/20…………Signature:……………………………
Or Thumbprint

If illiterate, please get a witness.

Witness statement

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely. I attest to the participant's voluntariness to join the study and appending of thumbprint or signature to signify consent to participate in this study.

Name of witness: ………………………………………………………..

Date (dd/mm/yyyy): …………/…………/20…………Signature:……………………………

To be completed by the Researcher/Representative

I certify that the nature and purpose, the potential benefits, and possible discomforts associated with participating in this research have been explained to the potential participant. I have answered all questions that have been raised and have witnessed the above signatures on the date indicated above.

Name of Researcher:…………………………………………………………………

Date (dd/mm/yyyy):………./………/20……………Signature:……………………..

Appendix G: Commercial and Household Cooking Practices Survey

Page 1

Commercial and Household Cooking Practices: GWAP study

Please complete the survey below.

Thank you!

1.1 Are you directly involved in gari frying	◯ Yes ◯ No
1 Is this form for GARI FRYER or CONTROL	◯ GARI FRYER ◯ CONTROL
2 Where do you usually fry the gari?	◯ Totally open(outdoors- no roof/ walls) ◯ Roof only (no walls) ◯ Veranda of a single house (1-2 walls and roof) ◯ Partially enclosed (2- 3 walls with no roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of compound (4 walls but no roof over cooking area) ◯ Fully enclosed(4 walls with roof) ◯ Inside veranda of compound (4 walls and roof only over cooking area). ◯ NA, no cooking area
3. If participants picks number 1 from Question 3.2, where do you usually fry the gari when it rains?	◯ Fully enclosed(4 walls with roof) ◯ Inside veranda of compound (4 walls and roof only over cooking area). ◯ NA, no cooking area ◯ Other:
3.1 If other, please specify	__________________________________
4 When do you use this cooking area?	__________________________________
5 Where is your household cooking area?	◯ Totally open (outdoors- no roof/ walls) ◯ Roof only (no walls) ◯ Veranda of a single house (1-2 walls and roof) ◯ Partially enclosed (2-3 walls with no roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of compound (4 walls but no roof over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Inside veranda of compound (4 walls and roof only over cooking area). ◯ NA, no second cooking area
6 When do you use this household cooking area?	◯ always use ◯ when it's dry ◯ when it's raining ◯ for certain meals ◯ NA, no secondary cooking area

projectredcap.org REDCap

7 What stove do you use most often to fry the gari?	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ wood stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: ◯ NA
7.1 If other, please specify:	______________________
8 What stove do you use most often in the household?	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ Improved wood stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: ◯ NA
8.1 If other, please specify:	______________________
9. For how long have you been cooking in this industry?	______________________

2. TIME ALLOCATED TO COOKING:

2.1 How long (in hours) a day do you typically take frying gari?	______________________ ([00=NA if no cooking; 0.5 for 30 mins; PLEASE ROUND TO NEXT HALF HOUR])
2.2 How long (in hours) a day do you typically cook in the household?	______________________ ([00=NA if no cooking; 0.5 for 30 mins; PLEASE ROUND TO NEXT HALF HOUR])
2.3 How often does the cooking in the household using the cookstove in Question 3.7 take place?	◯ Once in a day ◯ 2-3 times in a week ◯ 4-6 times in a week ◯ Seven times a week ◯ Others ◯ NA, No cooking
2.3.1 If other, please specify:	______________________

2.4 How often are you involved in the gari frying?	◯ Once in a day ◯ 2-3 times in a week ◯ 4-6 times in a week ◯ Seven times a week ◯ Others ◯ NA, No cooking
4.1 If other, please specify:	______________________

3 What is the main way that your household obtains the following fuels for cooking?

3.1 Firewood	◯ Gather, always ◯ Purchase, always ◯ Gather sometimes and purchase other times ◯ NA
3.2 Charcoal	◯ Burn/make own ◯ Purchase, always ◯ Make sometimes and purchase other times ◯ NA, Do not use Charcoal
3.3 Crop residue	◯ Gather, always ◯ Purchase, always ◯ Gather sometimes and purchase other times ◯ NA, Do not use Crop residue
3.4 Animal dung	◯ Gather, always ◯ Purchase, always ◯ Gather sometimes and purchase other times ◯ NA, Do not use Animal dung
3.5 Say: "I want to ask some questions about other activities that take place in your compound that may expose you to other sources of smoke."	____________________________

4. ABOUT RESPONDENT'S HOUSEHOLD MEMBERS

4.1 How many people above 15 years live in this household?	______________________ (([00 if none]))
4.2 In all how many people live in this household (woman inclusive)	______________________

5. FARM PLOT COOKING

5.1 Do you ever cook at your farm plot?	◯ Yes ◯ No ◯ NA, No farm plot
5.2 How many meals in a week do you cook on the farm?	______________________
5.3 How many months in a year do you cook on the farm?	______________________

6. TIME ALLOCATED TO COOKING AND FIREWOOD COLLECTION (HOUSEHOLD)

6.1 When the household gathers wood for cooking, how many people typically participate?

____
(([00=NA if no gathering of fuel wood]))

6.2 How long (in hours) does it typically take to gather wood?

____
(([00=NA if no gathering of fuel wood; 0.5 for 30 mins; PLEASE ROUND TO NEXT HALF HOUR]))

6.3 How often does wood gathering take place?

- ◯ Once in a week
- ◯ 2-3 times in a week
- ◯ Once in 2 weeks
- ◯ Once a month
- ◯ Others specify
- ◯ NA, No wood gathering

6.3.1 Please specify

____

7. TIME ALLOCATED TO COOKING AND FIREWOOD COLLECTION (GARI USERS)

7.1 When the workers gathers wood for frying Gari, do you participate?

- ◯ Yes
- ◯ No

7.2 How long (in hours) does it typically take to gather wood for frying the Gari?

____
(([00=NA if no gathering of fuel wood; 0.5 for 30 mins; PLEASE ROUND TO NEXT HALF HOUR]))

7.3 How often does wood gathering take place?

- ◯ Once in a week
- ◯ 2-3 times in a week
- ◯ Once in 2 weeks
- ◯ Once a month
- ◯ Others specify
- ◯ NA, No wood gathering

7.3.1 Please specify

____

8. Interview end time:

____

9. Comments

____

Appendix H: Enrollment and Respiratory Symptom Form

Enrollmentform_CassavaGritsPro

Please complete the survey below.

Thank you!

Maternal study ID	__________________________________
1. BASIC INFORMATION:	
1.1 Participant's Study ID	__________________________________
1.2. Participant's HDSS permID:	__________________________________
1.3. Participants' Name:	__________________________________
1.4 Community Name	__________________________________
1.4.1 District Name	__________________________________
1.5 Compound Number	__________________________________
1.6 Date of visit:	__________________________________ ((dd/mm/yyyy))
1.7 Interview start time:	__________________________________
1.8 Participants' Age	__________________________________
1.8.1 Respondent Gender?	◯ Male ◯ Female
1.9 Length of stay in community/district in (YEARS)	__________________________________ (Enter (NA) as not applicable)
1.9.1 Length of stay in community/district in (MONTHS)	__________________________________ (Enter (NA) as not applicable)
1.10 Fieldworker code:	__________________________________
1.11 Has consent been given?	◯ Yes ◯ No

1.12 Reasons for not consenting:	__________________________________
1.13 Is this form for GARI FRYER or CONTROL?	◯ GARI FRYER ◯ CONTROL

2. SOCIO-DEMOGRAPHIC CHARACTERISTICS:

2.1 What is your highest educational level?	◯ None ◯ Primary school ◯ Middle/JHS ◯ Technical/Commercial/SHS ◯ Post-middle training - teachers, secretarial, etc ◯ Post-sec training - Nursing, Teacher, Polytechnic, etc. ◯ University
2.2 Number of years completed at the highest educational level	___________________________ ([Enter 00 if No education i.e (2.1.1) =1])
2.3 Are you currently single, married, or living with a man, or are you widowed, divorced or separated?	◯ Married ◯ Living together with a man, unmarried ◯ Widowed ◯ Divorced ◯ Separated ◯ Single, unmarried
2.4 Do you have land on which you farm?	◯ Yes, my own ◯ Yes, part of family land ◯ Yes part of husband's ◯ Yes, rented land ◯ No
2.5 Which crops do you mainly grow on your land?	◯ Food items, mainly for home consumption ◯ Food items, mainly for sale on the market ◯ Cash crops: tobacco,cashew, cocoa, etc. ◯ NA, no farm
2.5.1 Do you have a regular cash income/are you a salaried worker?	◯ Yes, Professional: teacher, nurse,accounts, administrator etc ◯ Yes, Clerical/secretarial ◯ Yes, trader/food seller/businesswoman ◯ Yes, seamstress, hairdresser etc. ◯ Yes, Farmer/laborer/domestic worker ◯ No ◯ Other
2.5.1.1 If other, please specify.	___________________________

3. RESPIRATORY SYMPTOMS AND DISORDERS

These questions pertain mainly to your chest. Please answer yes or no if possible. If you are in doubt about whether your answer is yes or no, please answer no.

COUGH

3.1 Do you usually cough when you don't have a cold?	◯ Yes ◯ No
3.2 Are there months in which you cough on most days?	◯ Yes ◯ No
3.3 Do you cough on most days for as much as three months each year?	◯ Yes ◯ No
3.4 For how many years have you had this cough?	◯ Less than 2 years ◯ Two-Five (2-5) years ◯ More than 5 years

5. PHLEGM

5.1 Do you usually bring up phlegm from your chest, or do you usually have phlegm in your chest that is difficult to bring up when you don't have a cold?	◯ Yes ◯ No
5.2 Are there months in which you have this phlegm Yes on most days?	◯ Yes ◯ No
5.3 Do you bring up this phlegm on most days for as Yes much as three months each year?	◯ Yes ◯ No
5.4 For how many years have you had this phlegm?	◯ Less than 2 years ◯ Two-Five (2-5) years ◯ More than 5 years

6. BREATHLESSNESS

6.1 Are you unable to walk due to a condition other than shortness of breath?	◯ Yes ◯ No
6.1.1 What is the nature of this condition?	______________________________
6.2 Are you troubled by shortness of breath when hurrying on the level or walking up a slight hill?	◯ Yes ◯ No
6.3. Do you walk slower than people of your age on level ground because of shortness of breath?	◯ Yes ◯ No
6.4 Do you ever have to stop for breath when walking at your own pace on level ground?	◯ Yes ◯ No

6.5 Do you ever have to stop for breath after walking about 100 meters (or after a few minutes) on level ground?	◯ Yes ◯ No
6.6 Are you too short of breath to leave the house or short of breath on dressing or undressing?	◯ Yes ◯ No

7. RESPIRATORY DIAGNOSES

7.1 Has a doctor or other health care provider ever told you that you have emphysema?	◯ Yes ◯ No
7.2 Has a doctor or other health care provider ever told you that you have asthma, asthmatic bronchitis or allergic bronchitis	◯ Yes ◯ No
7.3 Do you still have asthma, asthmatic bronchitis or allergic bronchitis?	◯ Yes ◯ No
7.4 Has a doctor or other health care provider ever told you that you have chronic bronchitis?	◯ Yes ◯ No
7.5 Do you still have chronic bronchitis?	◯ Yes ◯ No
7.6 Has a doctor of other health care provider ever told you that you have chronic obstructive pulmonary disease (COPD)	◯ Yes ◯ No
7.7 Has a doctor or other health care provider ever had you blow into a machine or device in order to measure your lungs (i.e., a spirometer or peak flow meter)?	◯ Yes ◯ No
7.8 Have you used such a machine in the past 12 months?	◯ Yes ◯ No
7.9 Have you ever had a period when you had breathing problems that got so bad that they interfered with your usual daily activities or caused you to miss work?	◯ Yes ◯ No
7.10 How many episodes have you had in the past 12 months?	______________________ (([Enter = number in the boxes]))
7.11 For how many of these episodes did you need to see a doctor or other health care provider in the past 12 months?	______________________ (([Enter = number in the boxes]))
7.12 For how many of these episodes were you hospitalized overnight in the past 12 months?	______________________ (([Enter = number in the boxes]))

7.13 All together, for how many total days were you hospitalized overnight for breathing problems in the past 12 months?	______________________________ (([Enter = number in the boxes]))

8. SMOKING **Now I am going to ask you about smoking. First I will ask about cigarettes and then I will ask about other items that are smoked.**	
8.1 Have you ever smoked cigarettes?	◯ Yes ◯ No ((("Yes" means more than 20 packs of cigarettes in a lifetime or more than 1 cigarette each day for a year)))
8.2 How old were you when you first started regular cigarette smoking?	______________________________ ([Enter = age in the boxes])
8.3 If you have stopped smoking, how old were you when you last stopped?	______________________________ (([Enter = age in the boxes] (If the participant has not stopped smoking, record as '99')))
8.4 On average over the entire time you smoke(d), about how many cigarettes per day do (did) you smoke?	______________________________ (([Enter = number in the boxes]))
8.5 On average over the entire time you smoke(d), about how many cigarettes per week do (did) you smoke?	______________________________ (([Enter = number in the boxes]))
8.6 On average over the entire time you smoke(d), do (did) you primarily smoke manufactured or Hand-Rolled cigarettes?	◯ Manufactured ◯ Hand-Rolled
8.7 Have you ever smoked or inhaled any other Yes substance?	◯ Yes ◯ No ((e.g. water pipe, cannabis, cigars))
8.7.1 Please specify (1)	______________________________
8.7.2 Please specify (2)	______________________________
8.8 Not counting yourself, how many people in your household smoke regularly?	______________________________ (([Enter number in the boxes]))
8.9 Do people smoke regularly in the room where you Yes work	◯ Yes ◯ No

9. How many hours per day are you exposed to other people's tobacco smoke in the following locations?
[Enter = number of hours in the boxes] {need to specify what to put if answer is NA} {specify sum range 0-24}

9.1 At home?	________________
9.2 Bars, restaurants, cinemas, or similar social settings?	________________
9.3 In workplace?	________________
9.4 Elsewhere?	________________
9.5 Did your father ever smoke regularly during your childhood?	◯ Yes ◯ No
9.6 Did your mother ever smoke regularly during your childhood?	◯ Yes ◯ No
9.7 Did any other adult in your household ever smoke regularly during your childhood?	◯ Yes ◯ No

10. KNOWLEDGE, ATTITUDES AND PERCEPTIONS

10.1 Based on what you know or believe, does smoking tobacco cause serious illness?	◯ Yes ◯ No

11. Based on what you know or believe, does smoking tobacco cause the following:

	Yes	No
11.1 Stroke (blood clots in the brain that may cause paralysis)?	◯	◯
11.2 Heart Attack?	◯	◯
11.3 Lung Cancer?	◯	◯
11.4 Emphysema/COPD?	◯	◯
11.5 Chronic bronchitis?	◯	◯
11.6 Based on what you know or believe, does biomass smoke cause serious illness?	◯	◯

12. Based on what you know or believe, does biomass smoke cause the following:

	Yes	No
12.1 Stroke (blood clots in the brain that may cause paralysis)?	○	○
12.2 Heart Attack?	○	○
12.3 Lung Cancer?	○	○
12.4 Emphysema/COPD?	○	○
12.5 Chronic bronchitis?	○	○
12.6 Have you ever worked for a year or more in a dusty job?	○	○

12.6.1 For how many years have you worked in dusty jobs? ____________________________
(([Enter number in the boxes]))

13. ADDITIONAL CO-MORBIDITIES
Has a doctor or other health care provider ever told you that you had:

	Yes	No
13.1 Heart disease?	○	○
13.2 Heart failure?	○	○
13.3 Hypertension?	○	○
13.4 Diabetes?	○	○
13.5 Lung cancer?	○	○
13.6 Stroke?	○	○
13.7 Tuberculosis?	○	○
13.8 Are you currently taking medicine for tuberculosis?	○	○
13.9 Have you ever taken medicine for tuberculosis?	○	○
13.10 Have you ever had an operation on your chest in which a part of your lung was removed?	○	○
13.11 Were you hospitalized as a child for breathing problems prior to the age of 10?	○	○
13.12 Has a doctor or other health care professional told your father, mother, sister or brother that they had a diagnosis of emphysema, chronic bronchitis or COPD?	○	○

13.13 Has anyone living in your home (besides yourself) smoked a cigarette, pipe or cigar in your home during the past two weeks?	◯	◯

13.14 In the past 3 months, how many times have you taken antibiotics?	◯ 0-10 times ◯ >10 times

Comments

____

Appendix I: Exposure Monitoring Survey

PATs+ Exposure Monitoring.

Please complete the survey below.

Thank you!

1. BASIC INFORMATION	
1.1 Participant's Study ID	__________________________________
1.2 Participant's HDSS PERMID	__________________________________
1.3 Participant's name	__________________________________
1.4 Village name	__________________________________
1.6 Compound Number	__________________________________
1.6.1 Community Name.	__________________________________
1.6.2 District Name	__________________________________
1.7 Date of visit	__________________________________ ((dd/mm/yyyy))
1.8 Time of visit	__________________________________
1.9 Visit Round	◯ DAY 1 Consenting and Enrollment ◯ DAY 2 Deployment ◯ DAY 3 Follow-up, Spirometry and pickup
1.9.1 Is this form for GARI TRYER or CONTROL?	◯ GARI TRYER ◯ CONTROL
1.10 Staff code	__________________________________

COOKING FOOD

Ask the woman when she received the equipment and/or remind her of the last time you conducted the survey

2.1 Since you were given the monitor, have you cooked any meal?
- ◯ Yes
- ◯ No

MID-DAY MEAL ON THE FIRST DAY (DAY OF DROP-OFF)

2.1.1 Principal meal prepared?
- ◯ Fufu
- ◯ Tuo Zaafi (TZ)
- ◯ Banku
- ◯ Rice "balls"
- ◯ Rice
- ◯ Yam/Cassava/plantain/cocoayam
- ◯ Other, specify
- ◯ NA, did not cook

2.1.1.1 Please specify
____

2.1.2 For how many people?
____

2.1.3 Primary cook stove
- ◯ Open mokyia (stone/ mud/clay)
- ◯ Closed mokyia (stone/mud/clay)
- ◯ Metal mokyia
- ◯ Sawdust stove
- ◯ BioLite cook stove
- ◯ Coal pot
- ◯ Kerosene stove
- ◯ Gas stove
- ◯ Electric stove
- ◯ Other: Specify
- ◯ NA, did not cook

2.1.3.1 Please specify
____

2.1.4 Location for primary cookstove
- ◯ Totally open (outdoors- no roof/walls)
- ◯ Roof only (no walls)
- ◯ Veranda of single house (1-2 walls and roof
- ◯ Partially enclosed (2-3 walls without roof)
- ◯ Partially enclosed (2-3 walls with roof)
- ◯ In open courtyard of a compound (4 walls but no roof over cooking area)
- ◯ Inside veranda of a compound (4 walls and roof only over cooking area)
- ◯ Fully enclosed (4 walls with roof)
- ◯ Farm plot
- ◯ NA

2.1.5 Secondary cook stove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.5.1 Please specify	__________________________________
2.1.6 Location for secondary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.7 Did you use any charcoal?	◯ Yes ◯ No ◯ NA
2.1.8 Did it rain during cooking?	◯ Yes ◯ No ◯ NA
2.1.9 Was your child with you when you cooked?	◯ Yes ◯ No ◯ NA

EVENING MEAL PREPARED ON THE FIRST DAY (DAY OF DROP-OFF)

2.1.10 Principal meal prepared?	◯ Fufu ◯ Tuo Zaafi (TZ) ◯ Banku ◯ Rice "balls" ◯ Rice ◯ Yam/Cassava/plantain/cocoayam ◯ Other, specify ◯ NA, did not cook
2.1.10.1 Please specify	__________________________________
2.1.11 For how many people?	__________________________________

2.1.12 Primary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.12.1 Please specify	__________________________________
2.1.13 Location for primary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.14 Secondary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.14.1 Please specify	__________________________________
2.1.15 Location for secondary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.16 Did you use any charcoal?	◯ Yes ◯ No ◯ NA

2.1.17 Did it rain during cooking?	◯ Yes ◯ No ◯ NA
2.1.18 Was your child with you when you cooked?	◯ Yes ◯ No ◯ NA

MORNING MEAL PREPARED YESTERDAY (DAY AFTER DROP-OFF)

2.1.19 Principal meal prepared?	◯ Fufu ◯ Tuo Zaafi (TZ) ◯ Banku ◯ Rice "balls" ◯ Rice ◯ Yam/Cassava/plantain/cocoayam ◯ Other, specify ◯ NA, did not cook
2.1.19.1 Please specify	__________________________________
2.1.20 For how many people?	__________________________________
2.1.21 Primary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.21.1 Please specify	__________________________________
2.1.22 Location for primary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA

2.1.23 Secondary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.23.1 Please specify	__________________________________
2.1.24 Location for secondary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.25 Did you use any charcoal?	◯ Yes ◯ No ◯ NA
2.1.26 Did it rain during cooking?	◯ Yes ◯ No ◯ NA
2.1.27 Was your child with you when you cooked?	◯ Yes ◯ No ◯ NA

MID-DAY MEAL PREPARED YESTERDAY (DAY AFTER DROP-OFF)

2.1.28 Principal meal prepared?	◯ Fufu ◯ Tuo Zaafi (TZ) ◯ Banku ◯ Rice "balls" ◯ Rice ◯ Yam/Cassava/plantain/cocoayam ◯ Other, specify ◯ NA, did not cook
2.1.28.1 Please specify	__________________________________
2.1.29 For how many people?	__________________________________

2.1.30 Primary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.30.1 Please specify	__________________________________
2.1.31 Location for primary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.32 Secondary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.32.1 Please specify	__________________________________
2.1.33 Location for secondary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.34 Did you use any charcoal?	◯ Yes ◯ No ◯ NA

2.1.35 Did it rain during cooking?	◯ Yes ◯ No ◯ NA
2.1.36 Was your child with you when you cooked?	◯ Yes ◯ No ◯ NA

EVENING MEAL PREPARED YESTERDAY (DAY AFTER DROP-OFF)

2.1.37 Principal meal prepared?	◯ Fufu ◯ Tuo Zaafi (TZ) ◯ Banku ◯ Rice "balls" ◯ Rice ◯ Yam/Cassava/plantain/cocoayam ◯ Other, specify ◯ NA, did not cook
2.1.37.1 Please specify	__________________________________
2.1.38 For how many people?	__________________________________
2.1.39 Primary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.39.1 Please specify	__________________________________
2.1.40 Location for primary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA

2.1.41 Secondary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.41.1 Please specify	__________________________________
2.1.42 Location for secondary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.43 Did you use any charcoal?	◯ Yes ◯ No ◯ NA
2.1.44 Did it rain during cooking?	◯ Yes ◯ No ◯ NA
2.1.45 Was your child with you when you cooked?	◯ Yes ◯ No ◯ NA

MORNING MEAL PREPARED TODAY

2.1.46 Principal meal prepared?	◯ Fufu ◯ Tuo Zaafi (TZ) ◯ Banku ◯ Rice "balls" ◯ Rice ◯ Yam/Cassava/plantain/cocoayam ◯ Other, specify ◯ NA, did not cook
2.1.46.1 Please specify	__________________________________
2.1.47 For how many people?	__________________________________

2.1.48 Primary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.48.1 Please specify	__________________________________
2.1.49 Location for primary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.50 Secondary cookstove	◯ Open mokyia (stone/ mud/clay) ◯ Closed mokyia (stone/mud/clay) ◯ Metal mokyia ◯ Sawdust stove ◯ BioLite cook stove ◯ Coal pot ◯ Kerosene stove ◯ Gas stove ◯ Electric stove ◯ Other: Specify ◯ NA, did not cook
2.1.50.1 Please specify	__________________________________
2.1.51 Location for secondary cookstove	◯ Totally open (outdoors- no roof/walls) ◯ Roof only (no walls) ◯ Veranda of single house (1-2 walls and roof ◯ Partially enclosed (2-3 walls without roof) ◯ Partially enclosed (2-3 walls with roof) ◯ In open courtyard of a compound (4 walls but no roof over cooking area) ◯ Inside veranda of a compound (4 walls and roof only over cooking area) ◯ Fully enclosed (4 walls with roof) ◯ Farm plot ◯ NA
2.1.52 Did you use any charcoal?	◯ Yes ◯ No ◯ NA

2.1.53 Did it rain during cooking?	◯ Yes ◯ No ◯ NA
2.1.54 Was your child with you when you cooked?	◯ Yes ◯ No ◯ NA

OTHER EXPOSURES

3.1 Did you use any other stove apart from your primary cook stove for the following reasons since { instrument drop off}?

	Yes	No
3.1.1 Heating water for bathing or washing?	◯	◯
3.1.2 Making medicine?	◯	◯
3.1.3 Making tea	◯	◯
3.1.4 Cooking food for sale	◯	◯
3.1.5 Other?	◯	◯

3.1.5.1 Please specify __________________________________

OTHER EXPOSURES

4.1 Since { instrument drop off} have you

	Yes	No
4.1.1 Burned mosquito coils?	◯	◯
4.1.2 Used a kerosene lantern?	◯	◯
4.1.3 Use candles?	◯	◯
4.1.4 Smoked tobacco (cigarettes, etc)?	◯	◯
4.1.5 Burned bark of trees/other material to keep mosquitoes away	◯	◯
4.1.6 Done any roadside selling?	◯	◯
4.1.7 Made charcoal?	◯	◯
4.1.8 Other?	◯	◯

4.1.8.1 Please specify __________________________________

OTHER EXPOSURES

5.1. Since { instrument drop off} has anyone in your household done the following?

	Yes	No
5.1.1 Burned mosquito coils?	○	○
5.1.2 Used a kerosene lantern?	○	○
5.1.3 Use candles?	○	○
5.1.4 Smoked tobacco (cigarettes, etc)?	○	○
5.1.5 Burned bark of trees/other material to keep mosquitoes away	○	○
5.1.6 Other?	○	○

5.1.6.1 Please specify ______________________________

OTHER EXPOSURES

6.1 Since { instrument drop off} have you or anyone near you done the following?

	Yes	No
6.1.1 Trash burning?	○	○
6.1.2 Burning fields or grass?	○	○
6.1.3 Generator running?	○	○
6.1.4 Engine for grinding mill?	○	○
6.1.5 Other	○	○

6.1.5.1 Please specify ______________________________

OTHER EXPOSURES

7.1 Since { instrument drop off} has anyone in your compound

	Yes	No	NA
7.1.1 Used a 3-stone fire for any reason?	○	○	○
7.1.2 Used a coal pot?	○	○	○

COMPLIANCE

8.1 Was the participant's wearing the unit when you arrived?	◯ Yes ◯ No
8.1.1 If no, probe to find out why:	◯ Sleeping ◯ Bathing ◯ Forgot to put it on ◯ Other (specify) ◯ NA
8.1.1.1 Please specify	__________________________________

Day that the instrument was dropped off (yesterday)

	Yes	No
8.2 Did you remove the air monitoring device for sleeping (other than when you went to bed for the night)?	◯	◯
8.3 Did you remove the air monitoring device for bathing?	◯	◯
8.4 Did you remove the air monitoring device for any other reason?	◯	◯

YESTERDAY IN THE AFTERNOON OR EVENING

	Yes	No
8.5 Did you remove the air monitoring device for sleeping (other than when you went to bed for the night)?	◯	◯
8.6 Did you remove the air monitoring device for bathing?	◯	◯
8.7 Did you remove the air monitoring device for any other reason?	◯	◯

THIS MORNING

	Yes	No
8.8 Did you remove the air monitoring device for sleeping (after you woke up from your nighttime rest)?	◯	◯
8.9 Did you remove the air monitoring device for bathing?	◯	◯

8.10 Did you remove the air monitoring device for any other reason?	○	○
8.11 If yes to 8.7 or 8.10 - probe to find out why, see if there is a problem that you can address or that the study stove team can address	______________________________	
8.12 Form checked by	________________________	

Appendix J: PATs+ Setup Form

Setup PATS+ Data Sheet For 48 Hour Sampling

Please complete the survey below.

Thank you!

1.0 LAB SETUP	
1.1 Lab setup date and time	__________________________________ ((dd/mm/yyyy; hrs:mins))
1.2.1 Please specify	__________________________________
1.2 Laboratory setup by	__________________________________
1.3 PATS+ ID	__________________________________
1.5 Picture of PATS+ side showing outlet filter and PATS+ ID	(Take and upload picture)
1.6 Upload picture of PATS+ showing main round shaped filter in front	
1.7 Is this a duplicate deployment?	◯ Yes ◯ No
If yes to question 1.8, then two log forms need to be filled out.	
Make sure computer time is correct. Check with time on your phone. Adjust if needed. Ensure PATS+ time is synced with computer time.	
1.8 Is PATS+ device connected to the computer using USB micro cable (make sure the SD card is fully seated).	◯ Yes ◯ No
1.9 Open PICA software and select the Launch page.	◯ Okay
1.10 Fill the following data fields for reference.	◯ Okay
1.10.1 Note Gari Lung Function study	__________________________________
1.10.2 Label 1 Participant ID	__________________________________
1.10.3 Label 2 Participant's Age	__________________________________
1.10.4 Label 3 Compound ID	__________________________________

1.10.5 Label 4 District Name	__________________________________
1.11 Select the logging interval to 60 seconds by clicking the up and down arrows above the font 'log interval' option.	◯ Yes ◯ No
1.12 Next, click on PATS+ tab and enter Device Information accordingly	◯ Okay
1.12.1 Serial Number	__________________________________
1.12.2 Run state, Launched Waiting	◯ Yes ◯ No
Battery level should be 4.1 (100%) or 4.0 (85%)	
1.12.3 Battery level	◯ 4.1 (100%) ◯ 4.0 (85%)
1.12.4 If no, please continue charging PATS+ device before proceeding to 1.13	◯ Okay
1.13 Click the 'Sync Launch' button.	◯ Okay
1.14 A status window will open which says 'PATS+ Synced for Launch', click 'OK.'	◯ Okay
1.15 Disconnect the device from the computer. The PATS+ indictor LED will start flashing two red flashes every 6 seconds to show it is in standby mode.	◯ Okay (Ensure normal flow set to 0.5)
2.0 Zeroing the monitor (TO DO: PERFOM IN LAB WITH ZERO BOX)	
2.1 Before the PATS+ starts sampling, it must be in zero-particle environment for 10 minutes.	◯ Okay
2.2 Is the PATS+ in a clean, safe area out of direct sunlight.	◯ Yes ◯ No
2.3 Press and hold the PATS+ button until it changes from red to green and then release the button.	◯ Okay
2.4 Is PATS+ indicator LED is flashing red-green (every other second)?	◯ Yes ◯ No
If yes, place it in zero box with the intake hole exposed. The red-green indicator means that it is in the initial zeroing mode, which will last for 10 minutes.	
2.5 Repeat as quickly as possible for up to 4 PATS+ units (this is the maximum that will fit in a zero box).	◯ Okay

2.6 Close the box and pump 40 squeezes of air into the box using the squeeze pump.	◯ Okay
2.7 After 10 minutes (or when you see that the PATS+ lights are flashing green once every other second) open the box and check that the light is flashing green every two seconds. It is now in sampling mode.	◯ Okay
2.8 Put PATS+ devices in individual harnesses before setting out to the field	◯ Okay

3.0 BASIC INFORMATION

3.1 Participant's Study ID	________________________
3.2 Participant's HDSS permID	________________________
3.3 Participant's Name	________________________
3.4 Participant's age	________________________
3.5 Compound Number	________________________
3.6 Community Name	________________________
3.6.1 District Name.	________________________
3.7 Expected date of visit	________________________ ((dd/mm/yyyy))
3.8 Is this form for Gari fryer or control?	◯ Gari fryer ◯ Control

4.0 FIELD SETUP

4.1 Field set up by	◯ KZ ◯ WB ◯ SD ◯ Other (Specify)
4.1.1 Please specify	________________________
4.2 Field setup date and time	________________________ ((dd/mm/yyyy; hrs: mins))

4.3 Make participants wear the harness with PATS+	◯ Yes ◯ No
4.4 Explain to the participant that he or she can remove it when sleeping, bathing, or doing other activities for which it is not possible to wear the device.	◯ Okay
4.5 Fit the harness to the participant and show him or her how to adjust and remove it.	◯ Okay
4.6 Record placement and start time.	__________________________

5.0 FIELD PICKUP

5.1 Field take down by	◯ KZ ◯ WB ◯ SD ◯ Other (Specify)
5.1.1 Please specify	__________________________
5.2 Field pickup date and time	__________________________ ((dd/mm/yyyy; hrs: mins))
Note! Difference between Field setup date [fieldsetdt] and Field pickup date [pickupdt] is 48 hours	
5.4 Is the PATS+ still running	◯ Yes ◯ No

6.0 FINAL ZERO (TO DO: BRING MONITOR TO LAB)

6.1 Initials of staff member who backed up the files	◯ KZ ◯ WB ◯ SD ◯ Other (Specify)
6.1.1 Please specify	__________________________
6.2 Which computer	__________________________
6.3 At the end of the sampling period, press the PATS+ button and hold it until the LED changes from red to green, then release the button.	◯ Yes ◯ No
6.4 The flashing green-red-red LED every other second indicates that the end zeroing period has started.	◯ Okay
6.5 Immediately put the device in the zero box for the end zeroing period for about 10 minutes, using the same method for zeroing the PATS+ as described above.	◯ [Okay]

6.6 Repeat as quickly as possible for up to 4 PATS+ units (this is the maximum that will fit in a zero box).	◯ Yes ◯ No
6.7 Close the box and pump 40 squeezes of air into the box using the squeeze pump.	◯ Yes ◯ No
6.8 After the end zeroing period, the LED will start flashing double red and it can be taken out of the box.	◯ Yes ◯ No
6.9 Date and time of Final zero period	______________________

7.0 Downloading Data (TO DO: PERFOM IN LAB WITH MONITOR)

7.1 Date and time of download	______________________
7.2 Initials of staff member who is downloading the data from the PATS+	◯ KZ ◯ WB ◯ SD ◯ Other (Specify)
7.2.1 Please specify	______________________
7.3 Connect the device to the computer using USB micro cable.	◯ Yes ◯ No
7.4 Which Computer, Microsoft Surface Pro	◯ Yes ◯ No
7.5 Open PICA software.	◯ [Okay]
7.6 Click on the Device files and find serial number and date you deployed and pick up which you want to download from the Pats+ page.	◯ Okay
7.7 Device File number must match Device Information Serial Number from 1.12.1 at setup. Does it match?	◯ Yes ◯ No
7.8 If all matches, click download	◯ Okay
7.9 You should see the graph and the selected file details updated.	◯ Yes ◯ No
7.10 Then click on the Data tab, you should have the file you selected from the Pats+ page.	◯ Okay
7.11 Download a CSV extension file (recommended), click the 'Export to CSV File'.	◯ Yes ◯ No
7.12 Select a location (folder on desktop titled - PATS+ data files) where you want to save the file.	◯ Okay

7.13 Then click the 'save' button and the file will be saved at the selected location.	◯ Yes ◯ No

After each day of data is downloaded, turn the entire file into a zip file and email to the PI
Reminder - Delete files weekly from PATS+ after confirming PI has received and backed up because after 26 tests files are recorded, the PATS+ will beginning rolling over the oldest files.

Appendix K: Lascar Setup Form

lascar setup GWAP study

Please complete the survey below.

Thank you!

1. BASIC INFORMATION:

1) 1.1 Participant's Study ID ________________________

2) 1.2 Participant's HDSS permID ________________________

3) 1.3 Participant's Name ________________________

4) 1.4 Compound Number ________________________

5) 1.4.1 Community Name ________________________

6) 1.4.2 District Name. ________________________

7) 1.5 Village Name ________________________

8) 1.7 Date of visit: ________________________

9) 1. 8 Is this form for GARI FRYER or CONTROL
- ◯ GARI FRYER
- ◯ CONTROL

2. SETTING UP THE LASCAR MONITOR:

10) 2.1 Laboratory setup by ________________________

11) 2.2 Field set up ________________________

12) 2.3 Field take down ________________________

13) 2.4 Type of filter used
- ◯ Pre - weighted
- ◯ Dummy

14) 2.6 Lab setup date and time ________________________

15) 2.7 Is this a duplicate sample?
- ◯ Yes
- ◯ No

16) 2.8 Lascar ID ______________________

17) 2.9 Is the inner Filter ok?
- ◯ Yes
- ◯ No

18) 3.0 Ten (10) sec logging?
- ◯ Yes
- ◯ No

19) 3.1 Is the battery status ok?
- ◯ Yes
- ◯ No

20) 3.2 Is the centrifuge tube ok?
- ◯ Yes
- ◯ No

21) 3.3 Tea bags used?
- ◯ Yes
- ◯ No

22) 3.4 Field setup date and time ______________________

23) 3.5 Holder type
- ◯ Bag
- ◯ Harness

24) 3.6 Location of launch
- ◯ Health Facility
- ◯ Community

25) 3.7 Launch date and time lascar is disconnected from the computer. ______________________

26) 3.8 Deployment date and time when put on the participant ______________________

27) 3.9 Field Pick up date and time (when collected from the participant ______________________

28) 4.0 Which computer? ______________________

29) 4.1 Date backed up files to database /dropbox ______________________

30) 4.2 Initials of who back up the files ______________________

31) 4.3 ANY OTHER COMMENTS ______________________

Appendix L: Spirometer Form

Anthropometrics and Spirometry GWAP study

Please complete the survey below.

Thank you!

This form should be completed prior to and during the spirometry session. It will be administered by the health worker supervising spirometry.

Consent form must be checked before starting

1. BASIC INFORMATION:

1.1 Participant's Study ID: __________________________________

1.2. Processor HDSS permID __________________________________

1.3. Participants' Name: __________________________________

1.4 Community Name. __________________________________

1.4.1 District Name __________________________________

1.5 Compound Number __________________________________

1.6 Date of visit: __________________________________

1.7. Participants' Age __________________________________

1.9 Length of stay in community/district (YEARS) __________________________________
(Enter (NA) as not applicable)

1.9.1 Length of stay in community/district (MONTHS) __________________________________
(Enter (NA) as not applicable)

1.10 Is this form for GARI FRYER or CONTROL
- ◯ GARI FRYER
- ◯ CONTROL

2. SAFETY QUESTIONS:

	Yes	No
2.1 In the past three months have you had any surgery on your chest or abdomen?	◯	◯
2.2 Have you had a heart attack within the past three months?	◯	◯
2.3 Have you been hospitalized for any other heart problem within the past month?	◯	◯
2.4 Are you in the last trimester of pregnancy?	◯	◯
2.5 Are you currently taking medication for tuberculosis?	◯	◯
2.6 Is there some other reason why this participant should not perform the spirometry maneuver?	◯	◯

2.1 If YES, please specify: ______________________________

RECENT MEDICATION USE

3.1 Have you had a respiratory infection (cold) in the last three weeks?
◯ Yes
◯ No

3.2 Have you taken any medications for breathing in the last 24 hours?
◯ Yes
◯ No

3.2.1 How many times did you take the medications? ______________________

3.3 What medication(s) did you take for breathing in the last 24 hours? (MEDICATION 1) ______________________

3.3.1 What medication(s) did you take for breathing in the last 24 hours? (MEDICATION 2) ______________________

3.3.2 What medication(s) did you take for breathing in the last 24 hours? (MEDICATION 3) ______________________

3.4 How many hours ago did you last cook? ______________________
([Enter = number in the boxes])

4.1 Record the FVC first measurement. ______________________

4.2 Record the FEV1 first measurement. ______________________

4.3 Record the PEF first measurement

____

4.4 Record the FVC second measurement

____

4.5 Record the FEV1 second measurement

____

4.6 Record the PEF second measurement

____

4.7 Record the FVC third measurement

____

4.8 Record the FEV1 third measurement

____

4.9 Record the PEF third measurement

____

Inform the participants that you will next take their vital signs (i.e., blood pressure, pulse, height and weight)

4.7 Height (cm)

____
((cm))

4.8 Weight (kg)

____
((kg))

4.9 Pulse

____
((beats per minute))

4.10 Oxygen Saturation (%)

____

4.11 Systolic blood pressure (reading 1)

____

4.12 Diastolic blood pressure (reading 1)

____

4.13 Systolic blood pressure (reading 2)

____

4.14 Diastolic blood pressure (reading 2)

____

4.15 Systolic blood pressure (reading 3)

____

4.16 Diastolic blood pressure (reading 3)

____

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