Health risks associated with the production and usage of charcoal: a systematic review.

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ABSTRACT

Charcoal production and utilisation are linked to various health issues and occupational hazards. However, to our knowledge, no systematic review has primarily focused on the health implications of charcoal production and its use while distinguishing charcoal from other solid fuels such as wood and coal.

Objectives This systematic review presents a synthesis of the evidence on the health risks associated with producing and using charcoal across the world.

Design Systematic review using a systematic narrative synthesis approach.

Data sources MEDLINE (through Ovid interface), CINAHL, Embase, Web of Science, PsycINFO, Cochrane Library and SCOPUS, from inception to 26 February 2021.

Eligibility criteria for selecting studies Peer-reviewed journal articles reporting empirical findings on the associations between charcoal usage/production and health parameters.

Data extraction and synthesis Two independent reviewers extracted data and assessed the quality of primary studies.

Results Our findings showed that charcoal production and usage are linked with specific adverse health outcomes, including respiratory diseases (n=21), cardiorespiratory and neurological diseases (n=1), cancer (n=3), DNA damage (n=3), carbon monoxide (CO) poisoning (n=2), physical injury (n=2), sick house syndrome (n=1), unintentional weight loss and body mass index (BMI) reduction (n=2), increase in blood pressure (n=1) and CO death (n=1). Among the included articles that reported respiratory diseases (n=21), there was one case of asthma and tuberculosis and two cases of chronic obstructive pulmonary disease.

Conclusions This review links charcoal production/usage and some associated human health risks. These include respiratory diseases and other non-respiratory illnesses such as sick-building syndrome, cardiovascular diseases, DNA damage, CO poisoning and death, unintentional weight loss and BMI reduction, and physical injuries.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ The first systematic review to investigate health risks associated with charcoal production/usage by distinguishing it from other solid fuels such as wood and coal.
- ⇒ This study included evidence from a heterogeneous set of published works. As a result of this heterogeneity, finding studies of the same type (eg, population, setting, context) addressing the same health outcomes related to charcoal use and production was not always possible.
- ⇒ Some health outcomes were evidenced by a single study, although in some cases, this evidence showed a significant association.

INTRODUCTION

It is estimated that around 2.4 billion people globally depend on solid fuels (such as wood, dung, crop residues and charcoal) to meet their cooking, heating and other domestic needs.[1] This number can approach 3 billion if coal is included.[2] There are three main types of solid fuels used domestically. These are coal (fossil fuel), biomass (animal-based and plant-based) and charcoal. This review is focused on charcoal and the health impacts associated with the production and usage of charcoal. Emissions from solid fuels (eg, charcoal, wood, coal and animal dung) are different, with charcoal being regarded as a cleaner fuel in terms of emissions. Charcoal is produced from charring biomass (wood and various agricultural and forest residues), which is an incomplete combustion achieved through controlling the amount of oxygen present. The slow charring produces a black carbonaceous solid called charcoal that makes relatively smaller amounts of smoke (compared with other solid fuels) when used. Indoor solid fuel burning can expose human to significant amounts of smoke and other pollutants, especially in confined spaces. The incomplete combustion of solid fuels produces harmful smoke that poses substantial health risks. Biomass burning is associated with an inefficient combustion process and emission of a range of toxic substances,[3 4] including carbon monoxide (CO),[5 6] volatile organic compounds,[7] nitrogen oxides (NOx)[8] and polycyclic aromatic hydrocarbons (PAHs),[9–11] as well as fine particulate matter (PM).[12 13] These emissions constitute a significant source of indoor air pollution, particularly for households primarily dependent on biomass burning for cooking and heating. Charcoal is used as a domestic fuel for cooking and heating in many low/middle-income countries and as a barbecue fuel worldwide. Emissions from the charcoal result in serious problems, especially in sub-Saharan Africa, where indoor cooking is prevalent. Charcoal production in Africa constitutes more than 65% of global charcoal production.[14] It is known that burning charcoal poses fewer health risks compared with wood, making charcoal a fuel of choice for use in domestic settings due to reduced levels of smoke production.[15] Charcoal is a carbon-rich porous material that is produced through pyrolysis of organic matter (eg, wood) under controlled conditions (little or no oxygen supply) and commonly at temperatures of 200°C–400°C.[16] Charcoal smoke is a complex mixture of liquid, solid and gaseous components. Many are noxious, including but not limited to nitrogen, sulphur oxide, benzene, aldehyde, acrolein, organic acids, PAH and harmful PMs such as PM2.5 (PM with sizes <2.5 µm). These pollutants may cause cancer, heart and lung diseases, and can reduce the ability of the body to transport oxygen in the case of CO exposure. As a result, they can alter biological functions at the cellular level and lead to many abnormalities, such as slow reflexes and coagulation disorder.[17–20] Other health effects include perinatal conditions (eg, low birth weight, stillbirth), eye diseases (eg, cataracts) and associated diseases.[17]

Human health risk from exposure to charcoal emissions is greater when charcoal is burned indoors. The most vulnerable groups include children, pregnant or expectant women, nursing mothers, older adults, those with lung (eg, chronic obstructive pulmonary disease, COPD and asthma) and heart diseases and people of low socioeconomic status, such as homeless persons and persons with limited access to medical care.[21]

Charcoal producers are another group at risk of being exposed to harmful substances. Charcoal producers are involved in a range of activities, which include biomass sourcing, biomass transportation, biomass processing (eg, cutting, milling, drying), loading of biomass into the charcoal production units (eg, kilns), initiating and monitoring biomass charring process, the opening of kilns to remove the produced charcoal, handling of charcoal, packaging and transportation of charcoal to charcoal users. This range of activities exposes charcoal workers to large quantities of charcoal particles, smoke and dust. Each step of this process can be linked to several health risks reported in the studies included in this work. Charcoal production involves long hours of incomplete combustion of wood (used as feedstock), causing the release of noxious smoke gases.[22] Charcoal production has also been linked to other occupational health problems, including headache, dizziness, nose and acute eye problems, throat irritation, backache, sore hands, general exhaustion, chest pains, cough, heat burns and chest pains.[23–26] These are mainly experienced while felling and cross-cutting, kiln covering, breaking and management, as well as handling, transportation and distribution of the biomass used and the produced charcoal. Although there is growing evidence of the health risks associated with charcoal,[27 28] to the best of our knowledge, this subject has not been previously synthesised in a systematic review. In particular, no systematic review has explored charcoal-related health implications based on the type of activity (ie, production and usage). This evidence synthesis is particularly needed to guide policies and actions to identify health issues. Such policies could later provide solutions to prevent the identified health issues.

Objective of the review

The objective of this study is to conduct a systematic review of existing studies to synthesise the evidence on the health risks associated with the production and usage of charcoal worldwide.

METHODS

The protocol for the systematic review process has been registered in the International Prospective Register for Systematic Reviews (PROSPERO) (registration number: CRD42021213469) (online supplemental additional file 1).[29] Also, this systematic review is reported based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria.[29]

Deviations from the protocol

The deviations from protocol were as follows: (1) meta-analysis was not performed because of statistical and methodological heterogeneity of the included studies; (2) studies with intentional poisoning of charcoal, including suicide, were excluded; (3) studies which reported health risks of charcoal when combined with another biomass fuel (eg, wood) were excluded and (4) qualitative studies were excluded.

Search for articles

Search sources

An initial search was conducted in MEDLINE (through the Ovid interface) and CINAHL using a set of identified keywords. A second search was then undertaken across all the other included databases to identify relevant literature published from inception until 26 February, 2021: Embase (through Ovid) (1974–2021), MEDLINE (through the Ovid interface) (1946–2021), CINAHL (2021), Web of Science (Thomas Reuters) (1970–2021), PsycINFO (APA PsycNet) (1806–2021), Cochrane Library and SCOPUS (1960–2021). Thereafter, a third search was performed via the reference list of all included manuscripts. The corresponding authors of identified eligible studies, whose full texts were unavailable, were contacted through email to request the full texts. Searches were not restricted by publication date. On completion, the searches from each database were imported into the bibliographic manager EndNote V.X20, where duplicate citations were eliminated.

Search terms and strings

The research team developed the search strategy for this systematic review, and the first author revised and ran the searches (OSI). We searched for published articles on relevant databases based on relevant keywords according to the PEO (Population, Exposure, Outcomes) framework.[30] The search string and search strategy are reported in detail in online supplemental additional file 2. We used Boolean operators and wildcards to improve quality. Included studies must meet the PEO criteria. Reasons for the exclusion of an article were provided and reported according to the PRISMA guidelines.

Screening process

A two-staged screening process was used to assess the relevant studies. The title and abstract of the literature retrieved from the database search were screened by two independent reviewers: OSI and one of the coauthors (FVZ, LBDA, TP and EN). Full-text copies were obtained after the initial screening and were examined independently for eligibility by two reviewers: OSI and one of the co-authors (FVZ, LBDA, TP, KK). Discrepancies were resolved by discussions and consensus between the independent reviewers. Where there was a disagreement, a third reviewer (TP) was invited to decide on each discrepancy.

Eligibility criteria

Type of study

We included randomised controlled trials, non-randomised controlled trials, quasi-experimental, before-and-after studies, prospective and retrospective cohort studies, and cross-sectional studies. We excluded qualitative studies, reviews and systematic literature reviews, experimental animal studies, in vitro and in vivo studies, case studies, individual case reports, case–control studies, opinion pieces, editorials, comments, news, letters, and grey literature.

Condition or domain being studied

We included studies which explored the health problems associated with charcoal production and usage. The health issues included but were not limited to CO poisoning and lung problems such as cancer (respiratory tract and oral cavity), COPD and asthma.

Participants/population

Human studies, including participants of any age group, gender or ethnicity, that were carried out in any country were included. We excluded studies conducted on animal subjects.

Exposure (s)

Studies comprising the health effect of exposure to charcoal production and usage were included. We included studies that reported on exposure to harmful charcoal products (eg, smoke) in domestic applications (eg, residential heating, cooking and barbecue). Additionally, occupational exposure associated with charcoal production and industrial charcoal utilisation were included (examples include fish drying, cassava processing and bakery industries).

Outcomes

This systematic review synthesised the health problems associated with charcoal production and utilisation. This included but was not limited to respiratory diseases, including asthma, COPD, cystic fibrosis, lung cancer, tuberculosis (TB), bronchitis, pneumonia and emphysema. Other health outcomes included burning eyes, heart disease, stroke and early death.

We only included studies that reported data on the association between charcoal and health problems. We excluded studies where the association with health problems were reported by combining charcoal with other solid fuels (eg, wood, biomass, coal).

Study validity assessment

Included studies were assessed independently by two reviewers: OSI and one of the coauthors (FVZ, LBDA, TP and KK) using appropriate critical appraisal instruments from the JBI-MAStARI.[31] This included, but was not limited to, the JBI-MAStARI checklist for cohort studies, quasi-experimental, randomised controlled trials and analytical cross-sectional studies. JBI-MAStARI is the Joanna Briggs Institute Meta Analysis of Statistics Assessment and Review Instrument. Discrepancies were resolved by discussions and consensus between the independent reviewers. Where there was a disagreement, a third reviewer (TP) was invited to decide on each discrepancy.

Studies were categorised as having high, moderate and low risk of bias using the JBI critical appraisal checklist relevant for each type of study. The risk of bias was ranked as low when the study reached up to 49% of 'yes' scores, moderate when the study reached 50%–69% of 'yes' scores, and high when the study reached more than 70% of 'yes' scores.[31]

Data coding and extraction strategy

Data were extracted from the included papers using a standardised data extraction tool which was piloted and modified before its final use. Information extracted included: study characteristics (ie, authors, year, country); study design and setting; population (ie, sample, demographics); study duration; charcoal utilisation and dose; types of health outcome measured; data reporting association, predictive statistics and effect measures; and authors conclusion (online supplemental additional file 3).

Data extraction was carried out by two independent reviewers: OSI and one of the coauthors (FVZ, TP, LBDA and KK). Discrepancies were resolved by discussion, and if the disagreement was not resolved, a third reviewer (TP) was invited to make the final decision.

Potential effect modifiers/reasons for heterogeneity

Variation in measured outcomes may be caused by several factors, including study country, population, age group, type of exposure (producers or consumers), and exposure dose. We explored these variations in our narrative synthesis, and they were reported in the Review findings section of this paper.

Data synthesis and presentation

Because of heterogeneity across studies (including design, setting, outcome measures and analysis type), conducting a meta-analysis was not appropriate. Hence, only narrative synthesis was undertaken. The studies' characteristics and findings were synthesised using a systematic narrative synthesis approach and presented in a summary table (table 1).[32] To achieve this, the relevant data were collated, and results were presented as a review of descriptive statistics, and stratified according to the study design (ie, cohort, case–control, cross-sectional).

Table 1 Number of studies evaluating charcoal exposures and outcomes among producers and users

Health effect	Study design	Charcoal producer (N)	Charcoal user (N)	Grand total
Respiratory	Cross-sectional	5 (24, 27, 33, 38, 43)	7 (37, 44, 55–57, 66, 68)	14 (24, 27, 33, 37, 38, 43, 44, 55–57, 66, 68)
	Case–control	2 (22, 58)	2 (53, 59)	4 (22, 53, 58, 59)
	Cohort	2 (39, 50)	3 (36, 45, 46)	5 (36, 39, 45, 46, 50)
Cancer	Cross-sectional			
	Case–control		2 (63, 64)	2 (63, 64)
	Cohort		1 (62)	1 (62)
Death (CO)	Cross-sectional			
	Case–control			
	Cohort		1 (49)	1 (49)
Poisoning (CO)/carboxy haemoglobineamia	Cross-sectional		2 (47, 65)	2 (47, 65)
	Case–control			
	Cohort			
DNA damage	Cross-sectional	1 (40)		1 (40)
	Case–control	1 (67)	1 (48)	2 (48, 67)
	Cohort			
Physical injuries	Cross-sectional	2 (41, 61)		2 (41, 61)
	Case–control			
	Cohort			
Sick building syndrome	Cross-sectional		1 (52)	1 (52)
	Case–control			
	Cohort			
Cardiovascular	Cross-sectional		1 (51)	1 (51)
	Case–control			
	Cohort			
Multiple health outcomes	Cross-sectional		3 (42, 54, 60)	3 (42, 54, 60)
	Case–control			
	Cohort			
Unintentional weight loss and reduced BMI	Cross-sectional		2 (34, 35)	2 (34, 35)
	Case–control			
	Cohort			
Blood pressure	Cross-sectional		1 (69)	1 (69)
	Case–control			
	Cohort			
Grand total		13 (22, 24, 27, 33, 38–41, 43, 50, 58, 61, 67)	27 (34–37, 42, 44–49, 51–57, 59, 60, 62–66, 68, 69)	40

BMI, body mass index; CO, carbon monoxide.

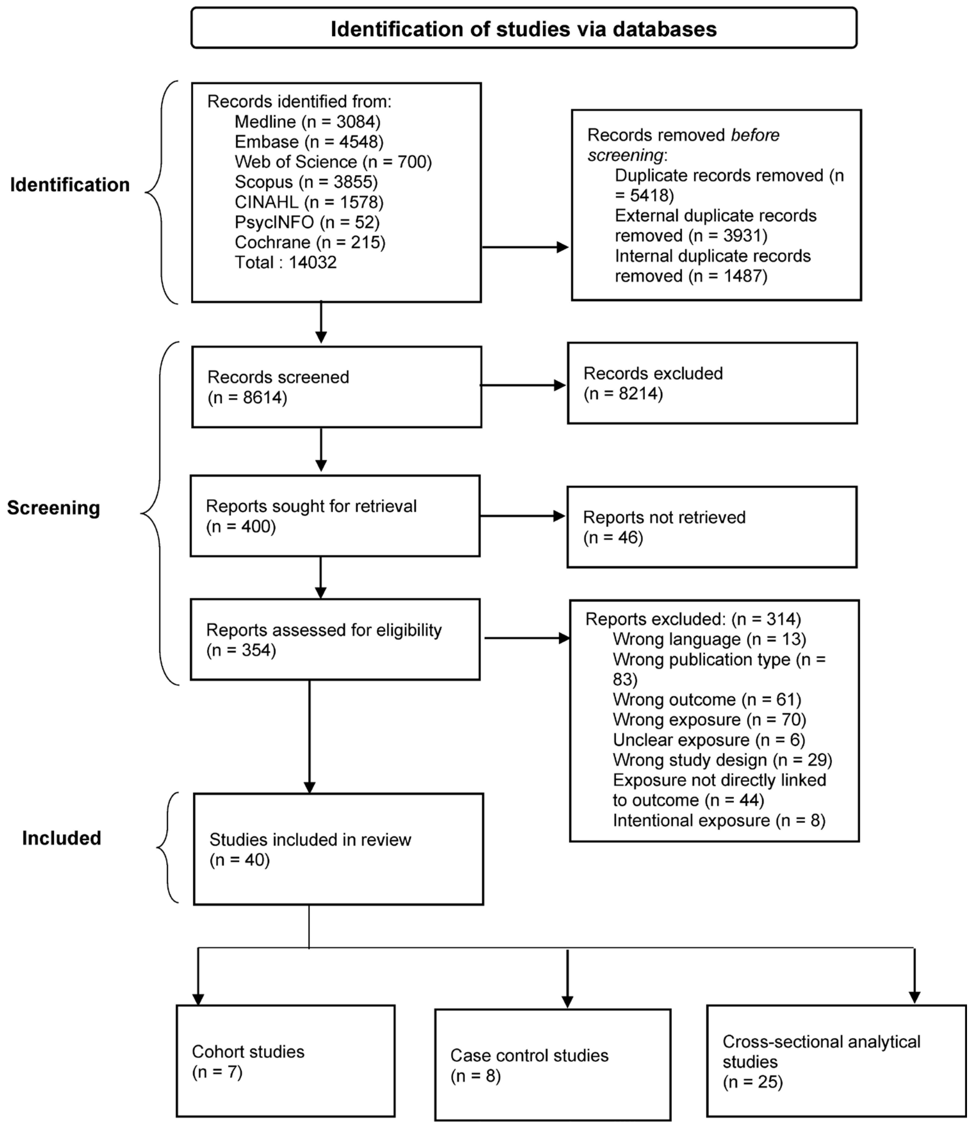

Figure 1 Selection of studies for inclusion in the systematic review.

Patient and public involvement

None

REVIEW FINDINGS

Review descriptive statistics

A total of 14032 papers were retrieved, of which 40 met the inclusion criteria (cohort studies,[8] case–control studies[7] and cross-section analytical studies[25]) and were included in the review (figure 1). Of the 40 studies included, 5 were conducted in Ghana,[33–37] 4 in Brazil.[38–41] Three studies were conducted in each of the following countries: Nigeria,[24 42 43] Uganda[44–46] and the USA.[47–49] Two studies were conducted in Thailand,[50 51] Ethiopia[52 53] and Malawi.[54 55] One study was conducted in each of the following countries: Burkina Faso,[56] Madagascar,[57] Greece,[22] Sri Lanka,[58] Dominican Republic,[59] Canada,[60] Liberia,[61] Morocco,[62] Namibia,[27] Tanzania,[63] Japan,[64] Bahrain,[65] Democratic Republic of Congo,[66] India,[67] Brunei.[68] In addition, one study combined 10 resource-poor countries: Albania, Armenia, Azerbaijan, Bangladesh, Benin, Ghana, Kyrgyzstan, Lesotho, Namibia and Peru[69] (see table 2).

Half (n=20) of the included studies were published between 2017 and 2021, while the remaining half were published from 1989 to 2016. The oldest included studies were published in 1989 (n=2).[48 58] Most of the

Table 2 Distribution by region for the included studies

Row labels	Percentage
Africa	56.8
Asia and Pacific	16.2
South/Latin America	13.5
North America	8.1
Arab States	2.7
Europe	2.7
Total	100.0

studies were on adults only,[22 24 27 33 34 36 38–52 54–69] while two were conducted on a combined population of adults and children.[35 37] Only one study included only children between 3 and 7 months old.[53] Overall, most of the studies were conducted among males and females (n=25),[24 27 33 36–39 43–47 49–53 55 57 59–61 63 64 68] five were conducted among male-only participants[22 40–42 66] and six were conducted among females only participants.[34 35 56 62 65 69]

Twenty-seven studies[34–37 42 44–49 51–57 59 60 62–64 66 68 69] were conducted among charcoal users. The majority used charcoal for cooking only (n=20)[34–37 42 44–46 48 51–54 56 57 59 65 66 68 69]; three used charcoal for heating and cooking,[47 49 55] while three studies reported that charcoal was used for medication,[60] tooth brushing[63] and cigarette filters.[64] Thirteen studies[22 24 27 33 38–41 43 50 58 61 67] were conducted among charcoal producers. The settings of the included studies varied between urban (n=7),[24 37 42 43 56 57 64] rural (n=5),[38 45 46 51 61] combined rural and urban (n=5),[34 36 54 55 69] hospital (n=5),[35 44 60 62 63] community (n=3)[53 66 68] and workplace (n=10).[22 27 33 39–41 48 50 58 67]

The included studies reported various outcomes. Most studies reported respiratory outcomes (n=21).[22 24 27 33 36–39 43–46 50 53 55–59 66 68] Three studies reported cancer,[62–64] and DNA damage,[40 48 67] two studies reported CO poisoning,[47 65] physical injury,[41 61] and reduced body weight and body mass index (BMI).[34 35] One study reported sick house syndrome,[52] cardiorespiratory and neurologic symptoms,[54] increased blood pressure[69] and CO-related death. Among the included studies which reported respiratory symptoms, there was one case of asthma[57] and TB[33] and two cases of COPD.[55 66]

Narrative synthesis, including studies validity assessment

Quality appraisal

A description of the quality appraisal scores of the studies is reported in figure 2. In total, 72.5% of the studies were considered high quality, 17.5% were moderate and 10% of the studies were low quality. Only one cohort study was considered high quality, four were moderate and two were low quality. Seven of the eight case–control studies scored high quality, and one was considered moderate quality. Most (n=38) of the cross-sectional studies scored high in the quality appraisal. From the remaining cross-sectional studies two studies were moderate quality and two studies were low quality.

Data synthesis

Data synthesis is provided in two modes: (1) according to the study design of the included studies and (2) according to participants' association with charcoal: charcoal producers and charcoal users.

Study designs

Table 1 lists the main health outcomes associated with charcoal production and usage. It highlights the study design for the included studies and the number of studies (of each type) presenting evidence for charcoal producers and users. The characteristics of these studies were detailed in online supplemental additional file 3.

Cohort studies

The study characteristics and findings of the cohort studies are provided in online supplemental additional file 3. A total of 2441 adults took part in the seven included studies,[36 39 45 46 49 50 62] aged between 27 and 56 years. The study duration varied between 0 and 10 years for the case–control and cohort studies. However, a follow-up of 12 months was only reported in one study.[62] Five[36 39 45 46 50] of the seven included studies reported respiratory outcomes, with common symptoms including chronic cough, phlegm with cold, dyspnoea and wheezing. In addition, one study reported cancer (lung cancer)[62] and one study reported CO poisoning.[49]

Case–control studies

The main characteristics and findings of the case–control studies are summarised in online supplemental additional file 3. A total of 2770 adults and children participated

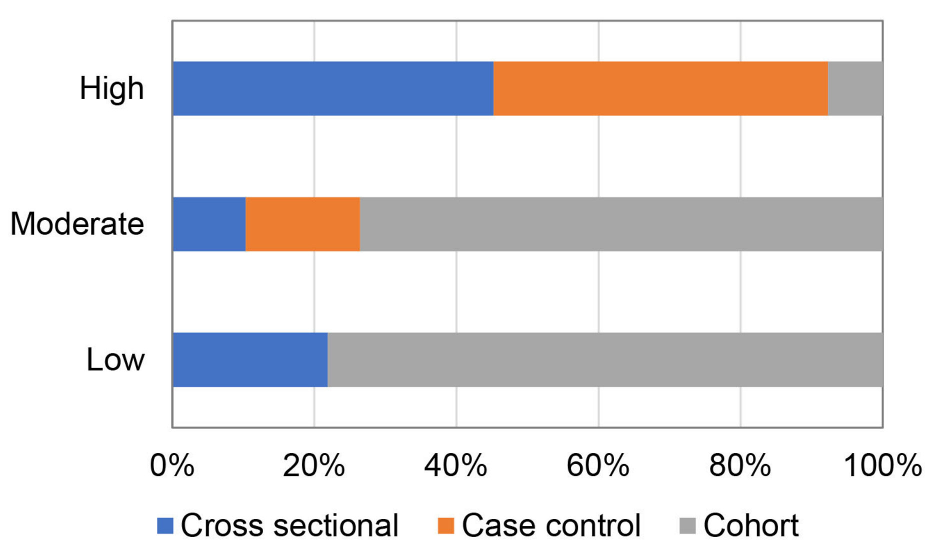

Figure 2 Quality appraisal of included studies.

in the eight studies of this type.[22 48 53 58 59 63 64 67] Participants aged between 2 and 63 years. Four studies[22 53 58 59] included reported respiratory outcomes. In addition, two studies reported cancer[63 64] (one lung cancer and oesophageal squamous cell carcinoma) and two studies reported DNA damage.[48 67]

Cross-sectional studies

A total of 18 389 adults and children took part in the 25 included studies of this type.[24 27 33–35 37 38 40–44 47 51 52 54–57 60 61 65 66 68 69] The participants were aged between 3 and 53 years. Twelve[24 27 33 37 38 43 44 55–57 66 68] of the 25 studies included reported respiratory outcomes. Two studies reported physical injury.[41 61] Two studies reported reduction in weight and BMI.[34 35] Two studies reported CO poisoning.[47 65] The following health outcomes were reported once in separate studies; sick house syndrome,[52] blood pressure increase,[69] DNA damage[40] and cardiovascular disease.[51] Three studies reported combined health outcomes.[42 54 60]

Charcoal producers and users

Data synthesis was performed considering the two groups of charcoal producers and charcoal users.

Charcoal producers

A total of 13 studies reported health outcomes associated with charcoal production.[22 24 27 33 38–41 43 50 58 61 67] Of these, nine studies evaluated respiratory outcomes,[22 24 27 33 38 39 43 50 58] two studies on physical effects[41 61] and DNA damage.[40 67]

Nine studies reported a significant association between charcoal production and respiratory health outcomes, but the respiratory outcomes reported varied.[22 24 27 33 38 39 43 50 58] Tzanakis *et al*[22] described that charcoal workers had increased respiratory symptoms, including cough (OR 4.8, 95% CI 1.2 to 19.7), sputum production (OR 6, 95% CI 1.4 to 26.5), wheezing (OR 7.7, 95% CI 1.4 to 41.5), dyspnoea (OR 28.7, 95% CI 5.4 to 153), haemoptysis (OR 2.7, 95% CI 0.7 to 55) and decreased pulmonary function. However, Souza *et al*[39] showed no increase in respiratory symptoms for 8 years except for sneezing, which increased by 29.4% ($p<0.05$). Another study reported that charcoal production was not the primary determinant of the higher prevalence of respiratory symptoms.[38] Therefore, several other factors associated with the worker or the workplace might have resulted in the increased respiratory symptoms, which were not identified in the study. Similarly, the study of Uragoda[58] showed no evidence of risk of developing pneumoconiosis for workers exposed to charcoal and pure carbon for up to a year.

On the other hand, studies showed that smokers were more likely to have respiratory outcomes such as impaired pulmonary function[38 39] and chronic bronchitis.[58] Certain types of activities during charcoal production result in increased odds of respiratory symptoms. Pramchoo *et al*[50] showed that loading of charcoal in kilns during production was associated with cough (OR 14.1, 95% CI 4.6 to 43.3), dyspnoea (OR 13.4, 95% CI 1.5 to 122), wheeze (OR 29.5, 95% CI 1.7 to 516) and sneeze (OR 11.9, 95% CI 2.9 to 48.2); while the collection of charcoal from kilns was associated with wheeze (OR 151, 95% CI 7.3 to 3120). Phlegm with cough was associated with either loading of kilns or collecting from kilns and firing kilns.

Exposure of charcoal workers to raw materials and the finished products can also lead to adverse outcomes.[24 27 33] Hamatui *et al*[27] showed exposure to high cumulative dust was associated with usual cough (OR 2.1, 95% CI 1.1 to 4.0, $p<0.05$), usual phlegm (OR 2.1, 95% CI 1.1 to 4.1, $p<0.02$), episodes of cough and phlegm (OR 2.8, 95% CI 1.1 to 6.1, $p<0.02$) and shortness of breath. The study also showed reduced lung capacity[27] and other air pollutants, including raised PM_{10} and $PM_{2.5}$ above the thresholds set in the WHO standards.[24] PM_{10} and $PM_{2.5}$ refer to the concentration of PM with a diameter of 10 microns or less and 2.5 µm or less, respectively. Similarly, TB has been associated with sawdust and exposure to smoke from charring wood during charcoal production.[33] However, some studies showed a dose–response relationship.[24 27] Hamatui *et al* showed that exposure to respirable charcoal dust levels at the highest dust exposure levels (median 27.7 mg/m3, range: 0.2–33.0 for the 8 hour time-weighted average) was significantly associated with usual cough (OR 2.1; 95% CI 1.1 to 4.0), usual phlegm (OR 2.1; 95% CI 1.1 to 4.1), episodes of phlegm and cough (OR 2.8; 95% CI 1.1 to 6.1) and shortness of breath. Two studies[41 61] investigated the risk of physical injuries, including musculoskeletal injuries, lacerations, infection, burns and death among charcoal producers due to work-related hazards including the use of axes and chain saws, heavy lifting, extreme high temperatures and inadequate safety training. One of the studies was conducted among males only,[41] and the second was among males and females, with 80% male participants.[61] Maia and Francisco[41] identified 96 postural events consisting of 7 activities and 17 subactivities of charcoal workers with the risk in the four levels of musculoskeletal injuries classified according to OWAS (Ovako Working posture Assessment System) method. The motions constituting risks and causing musculoskeletal harms to workers were shown to affect their health and productivity in the short, medium or long term (depending on the nature of the activity). Alfaro and Jones[61] reported a 75% injury rate among all respondents. The injuries included moderate to severe lacerations and burns of the lower extremities, death of a worker due to poor working conditions (three separate cases). Additionally, the majority of women participants expressed dizziness, light-headedness and nausea while, and for some time after, engaging in charcoal production activities.

Two studies examined the effect of exposure to charcoal on the DNA of workers and found a positive association between exposure and DNA damage.[40 67] Exposure to smoke during charcoal production was captured by higher levels of 2-naphtol (OR 17.3, 95% CI 6.91 to 42.44) and 1-hydrooxyprene (OR 11.55, 95% CI 5.32 to 25.08).

This was associated with urinary mutagenicity (OR 5.31, 95% CI 1.85 to 15.27).[40] Miglani *et al*[67] showed a higher 8-OHdG urinary concentration and TM content among charcoal workers with mutant *OGG1* genotypes, exposed to wood smoke and charcoal dust, therefore, the exposed charcoal workers were more susceptible to the oxidative and genotoxic DNA damage.

Charcoal users

Among charcoal users, 27 studies[34–37 42 44–49 51–57 59 60 62–66 68 69] reported health outcomes associated with charcoal utilisation. Of these, 12 studies[36 37 45 46 53 55–57 59 66 68] reported respiratory outcomes, 3 studies[62–64] reported cancer, 2 studies reported reduction of body weight and BMI issues,[34 35] 2 studies o reported CO poisoning,[47 65] 1 study reported DNA damage,[48] 1e study reported CO death,[49] 1 study reported sick house syndrome,[52] 1 study reported increase in blood pressure,[69] 1 study reported cardiovascular effects,[51] and 3 reported multiple health[42 54 60] outcomes.

Ten studies[36 37 44–46 53 56 57 59 68] that reported respiratory outcomes showed a positive association with the various respiratory symptoms, including cough, congestion, phlegm, wheezing, shortness of breath, among other symptoms. The effect of charcoal use on COPD was investigated in two studies,[55 66] and these studies showed a prevalence of COPD among charcoal users. The risk of respiratory symptoms increases in young children[37 59] and infants[36] exposed to charcoal smoke. Compared with firewood users, the odds of any respiratory symptoms[44 56] and COPD prevalence[66] were higher among women with charcoal exposure. In contrast, Owusu Boadi and Kuitunen,[37] Hussein *et al*[36] and Sana *et al*[56] showed higher respiratory symptoms among firewood users. There were conflicting findings regarding the use of charcoal in the open air and the respective health outcomes. Wolff *et al*[57] found no positive association between wheezing and charcoal use in an open fire. In contrast, a study conducted by Nazurah Bt Abdul Wahid *et al*[68] among open-air hawkers showed a positive association with respiratory symptoms compared with non-exposed merchandise sellers. Owusu Boadi and Kuitunen[37] reported that households who cook outdoors are less affected by respiratory health problems than those who cook in multipurpose rooms.

The use of charcoal was positively associated with CO-related death,[49] DNA damage,[48] sick building syndrome (SBS),[52] CO poisoning,[47] increased blood pressure[69] and carboxyhaemoglobinaemia.[65] Two of the three studies that compared charcoal exposure with cancer risk showed a positive association with lung cancer,[62 64] and the remaining one identified an association with oesophageal squamous cell carcinoma.[63] Additionally, two other studies investigated the association between charcoal use and cardiovascular and respiratory symptoms. Das *et al*[54] reported a positive association with cardiopulmonary health with symptoms such as shortness of breath (uphill and rest), tachypnoea, and dyspnoea, chest pain and some symptoms of respiratory disease, as well as other health outcomes, including forgetfulness, dizziness, difficulty concentrating, dry, irritated eyes, and burns. In contrast, Mato and Onajin-Obembe[42] reported no significant clinical respiratory symptoms or risk. However, in a study conducted in Thailand, charcoal users showed an increased risk of hypertension (OR 2.61, 95% CI 1.63 to 4.18), diabetes (OR 2.09, 95% CI 1.17 to 3.73), stroke (OR 3.17, 95% CI 1.04 to 9.71) and high cholesterol (HC) (OR 1.52, 95% CI 1.04 to 2.24)[51] from data on cardiovascular disease among 1078 households.

Charcoal use was associated with reduced body weight and BMI in women.[34] In addition, there was a significant exposure–response relationship between maternal exposure from charcoal use and birth weight,[35] with an increase in the risk of low birth weight (RR 1.41, 95% CI 0.62 to 3.23). Dorrington *et al*[60] investigated the effect of charcoal use on six categories of health outcomes, including pulmonary aspiration, gastrointestinal obstruction, hypernatraemia, hypermagnesaemia and corneal abrasion. The study found a significant association between pulmonary aspiration, hypernatraemia, hypermagnesaemia and a patient with cornea abrasion. However, no association was found between charcoal usage and gastrointestinal obstruction.

DISCUSSION

We summarise peer-reviewed journal papers on charcoal exposure and the associated health outcomes impacting charcoal users and producers. The identified health conditions/outcomes linked to charcoal use and production include respiratory diseases, cancers, death (from CO poisoning), CO poisoning, DNA damage, physical injuries, SBS, cardiovascular disease, reduction in weight and BMI, and increase in blood pressure. Some of these health conditions/outcomes were specific to charcoal producers or users (table 1); however, some were reported by both groups (table 2). A meta-analysis of the result was not conducted due to the high degree of variability of the study design, exposure settings and population groups. In what follows, the main findings are summarised and discussed.

Charcoal producers

Charcoal producers are exposed to pollution from charring of biomass during charcoal production. Among the producers, the most prevalent health outcomes are the respiratory effects. We found strong associations between exposure to charcoal and respiratory outcomes[22 24 38 39 50] TB[33] which are experienced at various stages of charcoal production. Additionally, the frequency and length of exposure as well as the raw materials used during production are shown to be associated with respiratory outcomes. Short-term exposure to the identified charcoal production hazards is also linked to these health outcomes.[22 50] Similarly, studies show that continuous work in charcoal production results in lung function decline.[39 50] This might be associated with wood smoke exposure during charcoal production. Wood smoke has been linked to decreased lung function, increased risk of respiratory symptoms, asthma and COPD.[70] Studies reported that tasks with the most significant effect due to exposure to wood smoke and charcoal dust involve entering into the kiln, including loading the kiln with fresh wood and collecting already fired charcoal from the inside of the kiln.[43 50]

The report shows that charcoal production workers were not provided with the necessary protective equipment to conduct their work safely at different stages of the process and in particular during the charring process.[22] On other occasions workers' health has been at risk due to the workers' negligence which is linked with lack of proper training on the subject of occupational health and safety.[24] Wood smoke generates complex mixtures of liquids, solids, gases and particles, including CO, CO_2, ammonia, NOx, PAHs, sulphur oxides, benzene, methanol, styrene, phenols, aldehydes and organic acids, which can result in short time irritation of the eyes, and mucous membrane of the upper respiratory tracts.[70 71] Obiebi and Oyibo[24] reported values of PM_{10} and $PM_{2.5}$ to be five times higher than the thresholds set by the WHO standards. Other air pollutants were also found to be significantly higher at the production sites. TB was reported among female workers within the charcoal production industry. This was associated with excessive exposure to wood smoke and sawdust.[33]

A few studies[41 61] also reported the risk of physical injuries depending on the nature of the activity, including moderate to severe laceration and burns of the lower outer extremities, which is common where proper workplace legislation is not in place.[61] In some cases, poor working conditions have resulted in death of the workers. The primitive tools (such as axes and chain saws), heavy lifting and extremely high temperatures used during charcoal production with no or little occupational health and safety training can result in moderate to severe injuries, which can be fatal. This becomes more significant particularly among rural dwellers who have little or no access to adequate medical care. A study reported a gender division exists in health outcomes which is associated with gender division of labour.[61] Common symptoms in women include dizziness, light-headedness and nausea.[61] However, these symptoms were not reported among male workers. Commonly, the role of male workers is collecting wood, assembling the kiln and initial firing, while female workers are involved with collecting and packaging the charcoal after the charring process has ended.[61] Maia and Francisco,[41] in their study of male charcoal producers, showed postural events linked to 7 activities and 17 subactivities associated with their risk of physical injuries using the OWAS method.[72] Further, DNA damage was reported among exposed charcoal workers during charcoal production following systemic exposure to a genotoxic compound.[40] Wood smoke has been shown to affect human health, with $PM_{2.5}$ from smoke resulting in biomedical changes.[73] Other emissions produced during charcoal production include benzene, toluene, naphthalene, substituted naphthalene, oxygenated monoaromatics and PAH.[74–76] There is evidence of mutagenicity associated with these wood smoke fractions.[77] Miglani *et al*[67] reported a significant association of polymorphisms *OGG1* heterozygous (*wt/mt*) and homozygous (*mt/mt*) with oxidative and genotoxic damage as a result of PAH exposure among charcoal workers in India. PAH exerts a toxic effect at a relatively low concentration,[67] and toxicity results from the imbalance between prooxidant and antioxidant homeostasis, leading to oxidative damage.[78]

Charcoal users

Charcoal users are mainly exposed to pollutants while burning charcoal for domestic use (eg, cooking and heating purposes). Therefore, the health impact becomes more severe for charcoal usage in indoor settings. We found strong associations between exposure to charcoal and respiratory outcomes, including chronic respiratory symptoms[36 44 46 56 57] and acute respiratory symptoms,[37 45 56 68] and acute respiratory infection (ARI).[53 59] The respiratory effect is the most prevalent health outcome among the users of charcoal compared with other health outcomes. In most studies, except one where charcoal was used for heating and cooling,[55] charcoal was principally used for cooking. There is evidence of higher CO releases from charcoal compared with other biomass[45] at levels above WHO guidelines, where charcoal is the primary cooking fuel. This higher CO levels has been linked to respiratory outcomes. Therefore, women[36 37 56 66] in low-income settings are usually the most affected due to their prolonged exposure to charcoal smoke as part of their cooking role.[44 55 79]

Similarly, the presence of children in environments where charcoal is used for cooking puts them at risk of respiratory symptoms,[37 57 59] with a higher risk among very young children being carried on the back.[53] Open-air use of charcoal also results in adverse respiratory outcomes, as seen with traditional barbecue cooking methods due to exposure to charcoal smoke.[68] North *et al*[46] found no relationship between cooking fuel and respiratory symptoms among males. Previous studies have shown an association between biomass use as cooking fuel and COPD.[80–82] Long-term exposure of the lung to air pollution results in increased resistance of small airways and the compliance of the lungs due to emphysematous destruction, resulting in airflow limitation in COPD.[83]

A study[52] showed a significant association between charcoal utilisation as a cooking energy source with SBS. SBS is when occupants of a building experience acute health-related or comfort-related effects that can be linked to time spent within the building.[84] Symptoms of SBS include headache, dizziness, nausea, eye, nose or throat irritation, dry cough, dry and itchy skin, difficulty in concentration, fatigue, sensitivity to odours, hoarseness of voice, allergies, colds, influenza-like symptoms, increased incidence of asthma attacks, and personality changes.[84] In addition, indoor charcoal utilisation generates gaseous pollutants associated with the incomplete combustion of charcoal.[85] This has adverse impacts on indoor air quality.

A study on unintentional CO deaths in California from residential and other non-vehicular sources reported an association with charcoal utilisation, which resulted in 22 deaths from charcoal used as heating fuels, among the 56 deaths linked to charcoal grills and hibachis (a traditional Japanese heating device). More deaths were reported during winter time when combustion appliances are used more frequently and for longer periods of time. Earlier studies in California show that many deaths were linked to misusing charcoal grills and hibachis.[86] In the USA, about 50 000 people visit the emergency department annually (ED) for accidental poisoning from CO and at least 430 deaths are recorded.[87] The high number of deaths and those who visited the ED could be attributed to the fact that people depend on alternative sources of power such as furnaces, stoves, lanterns and gas ranges or the burning of charcoal and wood during outages as a result of severe weather, which can cause CO to build up, and can result in loss of consciousness and death following CO inhalation.[87] Houck and Hampson[47] showed CO poisoning following a winter storm due to charcoal briquette use. In this study minority groups, including Asians and non-English speakers, are found to be the most affected groups. An early study among Asians showed that indoor cooking with charcoal briquettes is a common cause of CO poisoning.[88] Similarly, a study conducted in Bahrain among charcoal meat grilling workers showed a significant increase in carboxyhaemoglobin level in workers after their work day as a result of direct exposure to CO from incomplete charcoal combustion.[65]

The burning of charcoal results in exposure to hazardous substances, including CO and PM, from the emission of smoke. Similar to cigarette smoke, the use of charcoal is associated with lower body weight and BMI.[34 35] Studies on adult Ghanaian women showed an association between charcoal users with decreased BMI and body weight.[34] In addition, maternal charcoal use was associated with reduced foetal growth and low birth weight.[35] Our study also shows that the evidence on the link between cancer and charcoal production and use is not strong; therefore, more work must be done to examine this link.

A study reported a significant relationship between blood pressure and the use of charcoal[69]; however, the study was conducted among 10 countries, among which Ghana and Benin had the highest charcoal utilisation, with Ghana among those countries with the highest blood pressure. Across the countries studied, charcoal users had higher systolic blood pressure than electricity users. Similarly, charcoal was also associated with higher diastolic blood pressure than electricity use. Interestingly, the study identified that over 70% of rural women used solid fuels (charcoal and wood). Other studies have reported an association between $PM_{2.5}$,[89] CO exposure[90] and black carbon to changes in systolic blood pressure. Also, a recent worldwide study on blood pressure trends conducted in 2015 found the highest raised blood pressure in central and Eastern Europe, sub-Saharan Africa and South Asia.[91] The study of Arku *et al*[69] reported some factors (other than exposure to CO), including physical activity, ventilation and ambient temperature, among other factors that might affect the measured blood pressure. Therefore, further studies are needed to validate this outcome.

A study has established an association between charcoal-boiled food consumption and DNA damage among firefighters, with increased risk among those with higher current consumption of charcoal-boiled food.[48] Furthermore, Liou *et al*[48] showed that frequent consumption of charcoal-boiled food leads to more PAHs being metabolised to DNA-damaging species due to saturation of detoxifying enzymes. However, there is a need for more studies to confirm the genotoxic effect of charcoal-boiled food. In addition, DNA damage could result from pyrolysis products consumed with charcoal-boiled food. Wakabayashi *et al*[92] showed the presence of mutagens in fried beef due to the pyrolysis of amino acids.

One study[63] associated oesophageal cancer risk with use of charcoal for teeth whitening; however, no dose–response relationship was reported with the frequency of oral charcoal use. The use of oral charcoal can be associated with the risk of ingesting PAHs, which have been proven to result in oesophageal cancer.[93] Muscat *et al*[64] showed a significant association between charcoal cigarette filters and lung cancer, including adenocarcinoma, squamous cell carcinoma and small cell carcinoma in Japan. It is expected that using charcoal filters in cigarettes would reduce exposure to several gas-phase volatile compounds under Federal Trade Commission machine smoking conditions, with a lower yield of tar, CO, benzo(a) pyrene and tobacco-specific nitrosamines as reported in a previous study.[94] However, some toxins are associated with charcoal when used as filters. A study showed that the toxins are much higher in the last puffs due to desorption of the gas phase when charcoal becomes inactive.[95]

Similarly, Ismaili *et al*[62] found that exposure to smoke from charcoal was associated with lung cancer. However, they reported that squamous cell carcinoma was more frequent than adenocarcinoma, which was linked to a higher-level exposure to passive smoking. In contrast, Muscat *et al*[64] showed that adenocarcinoma was more prevalent than the other forms of lung cancer.

Exposure to charcoal smoke was strongly associated with cardiovascular diseases, including coronary heart disease (CHD), hypertension, diabetes and stroke.[51 54] Charcoal users had shown an elevated risk of CHD, hypertension, HC and diabetes. Previous studies show charcoal as a preferred category compared with other biomass fuels. Compared with biomass charcoal is higher on the energy ladder.[96] Energy ladder is a model used to describe household fuel choices in developing countries. In this model different energy-use patterns are linked with the economic status of households. In this classification charcoal falls into the transition fuels which are superior to primitive fuels such as wood and animal waste. Charcoal is associated with lower $PM_{2.5}$ exposure, but higher CO exposure above WHO recommended levels.[97] Exposure to CO in heavy tobacco smokers or people with heavy occupational exposure plays a role in developing cardiovascular disease due to the level of CO found.[98] A study has also reported a relationship between CO poisoning and cardiovascular complications, including myocardial stunning, left ventricular dysfunction, pulmonary oedema, arrhythmias and cardiac arrest.[99]

Review limitations

This study includes evidence from a heterogeneous set of published works. As a result of this heterogeneity, finding studies of the same type (eg, population, setting nd context) addressing the same health outcomes related to charcoal use and production was not always possible. This is, therefore, considered a limitation of this work. In addition, this review was limited because some health outcomes were evidenced by a single study, although this evidence showed a significant association in some cases.

REVIEW CONCLUSIONS

The body of evidence identified and presented in this review allows us to make robust conclusions regarding the most prevalent health implications of charcoal production and usage. To our knowledge, this study is the first systematic review focused on the health implications of charcoal production and use, particularly by distinguishing between charcoal and other solid fuels such as coal, biomass, wood and animal dung.

This review clearly links charcoal production and usage with respiratory health effects, including ARIs, COPD, lung cancer, asthma and TB. This association has previously been established by WHO. Additionally, this review found a clear association between charcoal production and usage and non-respiratory illnesses, including SBS, cardiovascular diseases, DNA damage, CO poisoning and death, unintentional weight loss and BMI reduction. However, we conclude that more work needs to be done to provide evidence and further explore the link between charcoal production and usage with health outcomes as, in some cases, evidence was not sufficient or strong enough to validate some of the identified health outcome.

Charcoal is considered a relatively cleaner fuel than wood, animal dung, coal and other agricultural residues; however, this study shows adverse health effects associated with charcoal, similar to other biomass fuels. Therefore, its use should be discouraged, particularly among rural dwellers, who depend on charcoal as their primary cooking and heating fuel, particularly in indoor settings.

This study concludes that charcoal production workers are adversely affected by occupational hazards associated with this industry. The main hazards identified and discussed in this review are physical (handling the feedstock and charcoal) and chemical (exposure to emissions from the charring process) hazards. Proper legislation for the charcoal industry can help with protecting charcoal production workers. The evidence discussed in this work shows that charcoal workers suffer from neglect associated with poor working practices, lack of training and insufficient enforcement of the use of personal protective equipment in the workplace by management.

There is also the need to promote cleaner and cheaper fuel use among rural communities. Therefore, government interventions should target cleaner and cheaper fuels. As an advantage of such long-term solutions, deforestation linked to the cutting of trees for charcoal production will be discouraged.

Implications for policy/management

The charcoal industry has been neglected, despite its social, cultural and economic importance. In 2020, charcoal production was estimated at 53.1 metric tonnes and export value at US$1.3 billion, with Africa alone at US$120 million.[100] However, most of the policy on charcoal has been focused on reducing threats to human health and deforestation by discouraging its use or making it more technologically efficient. Therefore, it is essential to differentiate the health effects associated with the production and usage phases. Some policy reports target the health effects of traditional biomass use for cooking and heating and its implication on indoor air quality and respiratory health.[101] According to the International Energy Agency, premature death from this type of respiratory problem is expected to rise above deaths due to malaria, TB and in sub-Saharan Africa, HIV/AIDS in 2030.[102] However, little is known about the health implication for the producers of charcoal in the extraction and production phases. Identifying these health risks will direct the attention of policymakers to the need to draw up a formal document for the safe production and use of charcoal. Effective enforcement of such regulations particularly protects the rural communities most affected by the adverse effects of charcoal production and usage. Charcoal producers and users must also be educated on the potential risks inherent in their job and other exposures.

Implications for research

Breathing smoke can take a long time to manifest as an illness. Nevertheless, the global community still needs to treat the health impact of polluting domestic fuels with an urgency commensurate with its effect, with rural communities and urban areas (particularly homes with more socioeconomic disadvantages) being the most affected. More studies must investigate the biomarkers relating charcoal utilisation to cancer types. In addition, research needs to include the impact of exposure to fine particles (mainly through inhalation) on members of communities with significant charcoal production activities. There is also a need to investigate the current state of policies around charcoal production and the drivers of such policies, and their enforcement in the workplace in countries with major charcoal production industries.

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