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Review

A review of diseases associated with household air pollution due to the use of biomass fuels

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ABSTRACT

Nearly one third of the world's population use biomass fuels such as coal, wood, animal dung, and crop residues as their primary source of domestic energy. Due to their incomplete combustion, a multitude of pollutants associated with high levels of indoor air pollution (IAP) are released which include suspended particulate matter (SPM), carbon monoxide, formaldehyde, nitrogen dioxide, polycyclic aromatic hydrocarbons (PAH), etc. There is a line of evidence that exposure to those pollutants can lead to increased risk of diseases including respiratory infections (e.g., pneumonia, tuberculosis and chronic obstructive pulmonary disease (COPD), lung cancer, and asthma), low birth weight, cataracts, and cardiovascular events. It is one of the major global public health threats that require greater efforts for prevention through research and policy-making. This review summarizes the available information on potential health risks associated with biomass fuel use.

Contents

1. Introduction

Being an important source of indoor air pollution (IAP), domestic energy source tends to be associated with significant morbidity and mortality. The status of the IAP can thus directly reflect the level and duration of exposure to deleterious pollutants [1]. Among various sources of IAP, the environmental significance of cooking activities has drawn a great deal of attention. Cooking-related IAP is known to be affected by the combined effects of fuel types, food materials, cooking styles, and so on.

Many types of pollutants are found to be released mainly from food materials and/or ingredients when food is fried, stir-fried, or grilled at a high temperature [2–6]. Like many deleterious substances produced from food materials via fire-based cooking, they are also emitted in the form of smoke and particles from cooking fuel. Those pollutants are identified to consist of volatile organic compounds (VOCs), carbonyls, carbon monoxide (CO), nitrous oxides, sulfur oxides (principally from coal), formalde-

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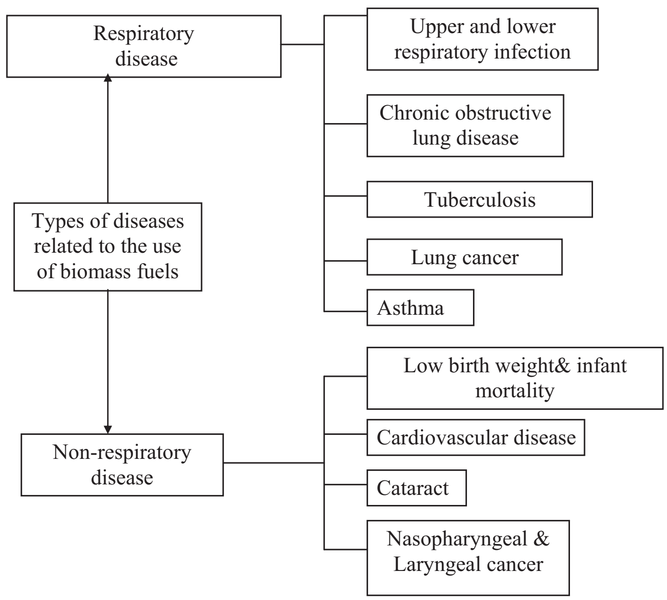

Fig. 1. The impact of biomass fuel smoke on respiratory and other diseases.

hyde, and polycyclic organic matter (e.g., carcinogenous benzo[a] pyrene) [7]. Approximately half the world's population and up to 90% of rural households in developing countries still rely on unprocessed biomass fuels in the form of wood, animal dung, and crop residues [8]. China, Korea, South Africa, and some other countries also extensively use coal for domestic needs [7]. These fuels are burnt indoors in open fires using poorly functioning stoves. As combustion is incomplete in most of these stoves, it can also serve as a key route to transfer high levels of indoor pollutants to those who are responsible for cooking and their family members. Exposure to IAP may be responsible for nearly 2 million excess deaths in developing countries and for some 4% of the global burden of disease [9]. Children are particularly vulnerable to IAP because their metabolic pathways are underdeveloped and immature [10]. In this article, we intended to explore the diverse health risks associated with cooking emissions in relation with the use of coal and biomass fuels. The overall picture of our coverage on these issues is briefly depicted in Fig. 1.

2. Type of fuel used for cooking

The energy requirement for cooking depends on many factors such as the type of food cooked, the number of meals cooked, household size, the specific combination of energy source, and cooking equipment employed (type of stove, cooking pans, etc.). Traditional biomass fuel is one of the major sources of domestic energy especially in the developing countries. About 2.4 billion people rely on traditional biomass, mainly for cooking and heating as they have limited access to better alternative energy sources like natural gas or electricity [8]. Biomass fuels are usually collected from the forests, agricultural residues, and the solid form of cow dung. Agricultural residues that have no particular use and cannot be composted easily end up as fuel. They include hay, jute stick, paddy husk, wheat stalks, dried leaves, date palm, sugarcane, bamboo (branches and roots), etc. In some cases, these energy sources are used simultaneously with fossil fuels like coal and kerosene. With the escalating price of coal and kerosene, rural people of the state are becoming more inclined to biomass for domestic cooking. The traditional home made cooking stoves cannot burn the fuels completely and emit a large amount of toxic air pollutants. In Table 1, emission factors of major pollutants released from biomass fuel are listed along with those of natural gas and liquefied petroleum gas (LPG) for comparison.

3. Respiratory diseases associated with cooking activities

As the major sources of IAP, combustion by-products released from heating and cooking can increase potential health risks (Table 2). There is now evidence linking an increased risk of cooking emissions with diverse diseases which include respiratory tract infections, exacerbations of inflammatory lung conditions, cardiac events, stroke, eye disease, tuberculosis (TB), and even cancer [15–20]. For instance, acute respiratory infections in children and chronic obstructive pulmonary disease in women are associated with indoor biomass smoke [21]. Lung cancer in women has also been found to be affected by household coal use [22]. The gaseous constituents released from the coal combustion have been found to be responsible for respiratory illnesses such as respiratory infections and bronchial asthma due to emission of gaseous pollutants [23]. Likewise, particles with diameters less than 10 (PM_{10}) and 2.5 μm ($PM_{2.5}$) are identified to exert damaging impacts, as they can penetrate deeply into the lungs [24]. In Table 3, exposure guidance levels established for several major pollutants that can also be released from biomass fuel burning are summarized along with their occurrence levels for reference. Moreover, health risks associated with biomass fuel burning relative to cleaner fuels (e.g., natural gas, LPG, etc.) are also presented in terms of odd ratio in Table 4. As the use of such data may allow to assess the capability of mitigation strategies, those pieces of information are very important for the establishment of various policies and the development of prevention strategies.

3.1. Upper and lower respiratory tract infections

Several studies have reported an association between exposure to biomass fuel smoke and general acute respiratory illness mostly in the upper respiratory tract, especially for children [28]. A clinic-based case-control study of children in rural New York State reported the cases of middle ear infection, otitis media involving two or more separate episodes for those who were exposed to wood-burning stoves [31]. Young children living in households combusting solid fuels have a greater risk of developing acute lower respiratory tract infection (ALRI) by two to three times more than those using cleaner fuels or those exposed less frequently to smoke [10]. Although otitis media is rarely fatal, it can cause much morbidity, including deafness. If untreated, it may progress to mastoiditis. In children under 5 years old, the ALRI-related mortality is estimated to exceed 2 million deaths per year [32]. Data from Ecuador and Kenya corroborate the risk of developing pneumonia and deterioration in lung function when children are exposed to high levels of pollutants from biomass fuel [33,34].

3.2. Chronic obstructive lung disease

Although the cause of chronic obstructive pulmonary diseases is commonly designated to cigarette smoking, they are also found frequently in countries of low smoking rate. Enormous studies have reported the association between exposure to biomass smoke and chronic bronchitis and/or chronic obstructive pulmonary disease [35–40]. Patients with chronic lung disease have been identified in communities heavily exposed to indoor biomass smoke pollution in New Guinea [41]. In Nepal, the prevalence of chronic bronchitis was similar between men and women (18.9%); this is unlikely to occur, if cigarette smoking, being more common in men, had been the main cause [36]. A similar scenario was also found in another study in Pakistan where chronic brochitis was greater in women despite their lower smoking rate [42]. As such, biomass fuel smoke can

Table 1
Emission factor (g kg^{-1}) of major pollutants from different types of domestic energy sources.

Pollutants	Fuel type						Reference
	Wood and leaves	Agriculture residue	Cow dung	Coal	Natural gas	LPG	
CO	80.2	75.5	83.2	74.2	0.11	1.03	[11]
	76.3	64.4	77.1	–	–	–	[12]
	80.0	79.1	61.3	74.8	0.49	1.12	[13]
PM	9.30	7.44	20.6	23.2	0.01	2.2	[11]
	7.43	10.2	23.6	–			[12]
	–	–	–	26.3			[14]
SO_2	0.34	0.29	6.42	13.1	0.05	20.2	[11]
	0.44	0.19	5.12	–			[12]
NO_X	2.34	1.74	7.16	1.42	0.53	2.74	[11]
	1.98	2.43	5.82	–			[12]
VOCs	6.71	–	–	1.93	0.01	0.41	[11]

Table 2
Mechanism and potential health effects from biomass fuel smoke emission.

Pollutant	Mechanism	Potential health effects	References
Particles matter (less than 10 μm aerodynamic diameter)	Acute: bronchial irritation, inflammation and increased reactivity	Wheezing, exacerbation of asthma	[1,7,21]
	Reduced mucociliary clearance	Respiratory infections	
	Reduced macrophage response and reduced local immunity	Chronic bronchitis and chronic obstructive pulmonary disease	
	Fibrotic reaction	Exacerbation of chronic obstructive pulmonary disease	
Carbon monoxide	Binding with hemoglobin to produce carboxyhemoglobin, which reduces oxygen delivery to key organs and the developing fetus	Low birth weight (fetal carboxyhemoglobin 2–10% or higher)	[9,13,15]
		Increase in perinatal deaths	
Polycyclic aromatic hydrocarbons, e.g., benzo[a]pyrene	Carcinogenic	Lung cancer	[17,20,21]
		Cancer of mouth, nasopharynx and larynx	
Nitrogen dioxide	Acute exposure increases bronchial reactivity	Wheezing and exacerbation of asthma	[1,10,21]
	Long term exposure increases susceptibility to bacterial and viral lung infections	Respiratory infections	
		Reduced lung function in children	
Sulfur dioxide	Acute exposure increases bronchial reactivity	Wheezing and exacerbation of asthma	[9,18]
	Long term: difficult to dissociate from effects of particles	Exacerbation of chronic obstructive pulmonary disease, cardiovascular disease	
Biomass smoke condensates including polycyclic aromatics and metal ions	Absorption of toxins into lens, leading to oxidative changes	Cataract	[19,21]

Table 3
Exposure guidance levels (in μg m^{-3}) of key pollutants that are also emitted from biomass fuel burning.

Pollutant	NIOSH REL[a] (8 h)	ACGIH TLV[b] (8 h)	OSHA PEL[c] (8 h)	Biomass fuel emission	References
Particulate matter (PM)	1000	500	15,000	300–3000	[25–28]
Carbon monoxide	40,000	29,000	55,000	2290–57,300	[25–28]
Nitrogen dioxide	45,000	90,000	–	81–256	[25,26,29]
Sulfur dioxide	5000	650	13,000	53	[25–27,30]

[a] The National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) in 1992 [25].
[b] The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) in 1994 [26].
[c] The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) in 2006 [27].

Table 4
Health outcomes associated with biomass fuel users compared with cleaner fuels (e.g., natural gas, LPG, etc.).

Order	Disease type	Odd ratio	95% CI	Reference
1	Chronic respiratory diseases	3.85	1.11–13.8	[36]
2	Tuberculosis	3.56	2.82–4.50	[46]
3	Lung cancer	5.33	1.74–16.7	[51]
4	Stillbirth	1.51	1.26–1.85	[69]
5	Rapid breathing	2.24	1.23–4.22	[10]
6	Acute lower respiratory infection	1.56	1.24–1.97	[33]
7	Blindness	1.30	1.21–1.95	[28]
8	FEV1/FVC	3.11	1.63–5.94	[30]
9	Chronic phlegm	2.00	1.2–3.4	[7]

develop chronic obstructive pulmonary disease (COPD) with clinical characteristic and mortality similar to that of tobacco smokers [43,44]. In rural Mexico, the use of biomass fuel was designated as the cause of a 4% decrease in lung function tests (e.g., forced expiratory volume in 1 s (FEV1), forced vital capacity (FVC), etc.), while an increase in the kitchen particle concentration of 1000 mg m^{-3} can lead to 2% reduction in FEV1 [45]. However, in damp and unhealthy indoor environments, various microorganisms (e.g., gram negative bacteria, molds, etc.) tend to grow which can be responsible for COPD and asthma. There is however no direct relationship between these microorganisms and the type of domestic fuels.

3.3. Tuberculosis

Tuberculosis (TB) is a major infectious cause of illness and death worldwide, while its occurrence (and deaths) is more dominant in Asia and Africa. Although IAP is not the direct cause of such disease, pollution arising from biomass fuels has been implicated to accelerate the infection of TB and/or related diseases [46,47]. Mishra et al. [46] also found substantially higher prevalence of active tuberculosis in some Indian residents who primarily use biomass for cooking with odds ratio [OR] = 3.56 (2.82–4.50: 95% confidence interval [CI]). In another investigation in Nepal, the rate of TB was seen to be higher from the use of a biomass-fuel stove than that of a stove with cleaner fuels (e.g., liquefied petroleum gas, biogas, etc.) [48]. Biomass fuel smoke is known to impair alveolar macrophage function [49]. Note that alveolar macrophages contribute to build up of an important, early defense mechanism against bacteria responsible for TB [47]. Therefore, it seems intuitive that biomass fuel smoke can also lead to an increased incidence of TB. However, more epidemiological and laboratory data are needed to corroborate this statement further.

3.4. Lung cancer

Lung cancer is a multifactor-causing disease. Results of numerous studies coincide in that domestic coal smoke is a significant risk factor for the development of lung cancer [50]. In India and Mexico, research was carried out to investigate the health risks of non-smoking women exposed to biomass smoke for a number of years. The results of those studies suggest that long-term exposure from cooking should contribute to the development of adenocarcinoma of the lung [51,52]. The International Agency for Research on Cancer (IARC) recently termed biomass smoke as a probable carcinogen (Group 2a) and coal (used as domestic fuel) as Group 1 carcinogenic [53].

In some homes, women who cook 3 h per day can be exposed to similar amounts of benzo[a]pyrene that can be inhaled via smoking two packets of cigarettes daily [54]. The toxins and carcinogens released from biomass fuel can make the lung tissues more prone to develop cancer than normal tissues. Whatever the mechanism, exposure to biomass smoke is a potential risk factor for lung cancer. Chinese women engaging routinely in home cooking were found to have significantly higher levels of mercapturic acids of acrolein (1959 pmol mg^{-1}), crotonaldehyde (232 pmol mg^{-1}), and benzene (0.58 pmol mg^{-1}) which are multi-organ carcinogens [55]. Pan et al. [56] found oxidative damage of DNA from Chinese restaurant workers exposed to cooking oil fumes. In another study in Europe (Czech Republic, Hungary, Poland, Romania, Russia, Slovakia, and United Kingdom), lung cancer risk from solid-fuel based cooking was seen to be moderately high relative to nonsolid counter part [20]. In another study conducted in Hong Kong, about 27% of lung cancer was attributed to exposure to cooking emissions [57]. This type of results, in turn, corroborated the significance of cooking fumes as a risk factor for lung cancer. Shields et al. [58] reported that 1,3-butadiene, benzene, acrolein, formaldehyde, and other related compounds were detected from the use of unrefined Chinese rapeseed oil. Although the effects of oil burning may be distinguished from those released directly from fuels, high-temperature wok cooking with unrefined Chinese rapeseed oil has also been designated as the main cause of the high lung cancer rate of Chinese women [59].

3.5. Asthma

Bronchial asthma is a common health problem worldwide. Several studies found positive associations between biomass smoke and asthma in children and adults [60,61]. A case-control study was carried out against children asthmatic patients aged between 1 month and 5 years in Kuala Lumpur, Malaysia [60]. This study identified the use of kerosene or wood stoves as the main cause of disease. In a study conducted in rural China, enhanced rate of wheezing and asthma was also observed for a group exposed occupationally to wood or hay smoke, respectively [62]. Similarly elevated risks were also reported for those using coal for cooking. Behera et al. [39] found that exposure to biomass fuel and LPG affect the airway function, pulmonary function (PEFR) in asthmatics, and symptoms of bronchial asthma in a similar manner.

Chronic exposure to biomass fuel combustion produces significant bronchial hyper-responsiveness [63]. Moreover, such exposure can also cause transient airway narrowing or airway inflammation through irritation. Thus, they may increase the risk of bronchial asthma or exacerbations of the pre-existing disease [39]. The indoor levels of SO_2, NO_2, and suspended particulate matter (SPM) were significantly greater in houses where the cooking was made on coal, wood, kerosene and cow dung cake compared to LP gas [61]. A number of disease (asthma, rhinitis, and upper respiratory tract infection) were thus diagnosed from children residing in those homes.

4. Non-respiratory illness

Indoor air pollution resulting from the use of biomass fuels can cause enormous health burden apart from respiratory illness. A tight relationship is thus expected to exist between such activities and an increased risk of non-respiratory illness such as: low birth weight in neonates, nutritional deficiencies, cardiac events, stroke, eye disease, nasopharyngeal, and laryngeal cancer [64–66].

4.1. Low birth weight and infant mortality

A line of evidence is now built up to explain the possible relationship between exposure to biomass fuel smoke and reduced birth weight. A number of authors specifically reported their association with carbon monoxide [67,68]. A study from Guatemala demonstrated that birth weight of new born babies is affected by the type of fuel used [69]. The babies of mothers using open wood fires were on average 63 g lighter than those using cleaner fuels like gas or electricity. A similar result has also been observed in Zimbabwe, Ecuador, and Czech Republic [70,71].

Even infants of normal birth weight are found to suffer from respiratory mortality and sudden infant death syndrome under high exposure of indoor air pollutants. A study in Mexico City examined the relationship between fine particles and the infant mortality rate [72]. The strongest effect was observed from $PM_{2.5}$ levels, as an excess infant mortality rate of 6.9% was seen at $PM_{2.5}$ values of 10,000 $\mu g\ m^{-3}$. A study from USA also made a similar report in which an excess perinatal mortality can result from enhanced PM_{10} concentration [73].

Biomass smoke is a complex mixture of pollutants including PM, CO, and others. As PM can penetrate deep into the lungs, it can compromise host defense mechanisms or increase respiratory infection risk of infants [74,75]. Acute exposure to PM causes bronchial irritation, inflammation, and reduced mucociliary clearance, all of which can lead to the aggravation of infant mortality [74]. In houses using biomass fuel, the mean 24-h PM_{10} levels have been 300–3000 $\mu g\,m^{-3}$ and can reach up to 30,000 $\mu g\,m^{-3}$ [28]. Note that the recommended exposure limit set for PM_{10} exposure is 1000 $\mu g\,m^{-3}$ for 8-h by national institute for occupational safety and health [25]. Inhaled CO, if bound with hemoglobin, can exert systemic biologic effects to produce carboxyhemoglobin through which oxygen delivery to vital tissues is interrupted [76]. As a result, chronic exposure to CO can contribute to low birth weight and an increase in perinatal deaths. Although an IAQ guideline is set for CO at 25 ppm for 8-h duration [26], its mean values in homes using biomass fuel are typically in the range of 2–50 ppm and as high as 500 ppm (during cooking) [28].

4.2. Cardiovascular disease

The level of particulate air pollution can be an indirect barometer to assess the rate of cardiovascular disease [77]. Based on long-term studies of PM, it is now possible to confirm a relationship between $PM_{2.5}$ and an elevated risk of cardiovascular disease [78,79]. Another study has shown that non-fatal ischaemic events are also affected by an increase in fine particulate concentrations in the community [80]. Likewise, exposure to biomass smoke has been demonstrated to increase diastolic blood pressure of Guatemalan women [81]. PM pollution was also seen to induce rapid and significant increases in fibrinogen, plasma viscosity, platelet activation, and release of endothelins, a family of potent vasoconstrictor molecules [77]. It is anticipated that CO can principally affect tissue oxygenation through carboxyhemoglobin production to ultimately impact cardiovascular function [76]. As the smoke released from biomass fuel is a major source of PM and CO, it has the potential to activate neutrophils, monocytes (white blood cells), and platelets [82]. Platelets are blood cells that help blood coagulation which forms blood clots inside the blood vessels. Therefore, biomass fuel smoke can pose considerable risk to cardiovascular health.

4.3. Cataracts

Indoor air pollution derived by biomass fuel combustion can cause eye irritation and/or cataract (or blindness) [83]. Epidemiological studies from Nepal and India suggested a possible link between biomass fuel smoke and cataracts [19,84]. Smoke can induce oxidative stress, as it depletes the antioxidant protection against cataract formation (like plasma ascorbate, carotenoids, and glutathione). Based on an analysis of over 170,000 people in India, Mishra et al. [46] reported higher partial (or complete) blindness of those who use mainly biomass fuel relative to other fuels. Animal studies have also shown that wood smoke condensates and damages the lens of rats, then producing discoloration, opacities, and particles of debris. The mechanism is thought to involve absorption and accumulation of toxins that can facilitate oxidation [46]. However, radicals present in biomass fuel smoke can attack the eye directly, potentially damaging lens proteins and the fiber cell membrane in the lens [83].

4.4. Nasopharyngeal and laryngeal cancer

Biomass smoke has been implicated as the cause of nasopharyngeal carcinoma [85]. The results of a case-control study in Brazil indicate that oral cancer was directly affected by tobacco, alcohol, and the use of wood stoves [86]. In another study from Brazil, the prevalence of oral, pharyngeal, and laryngeal cancer was observed from those exposed to wood smoke instead of cleaner fuels [87]. It was estimated that exposure to wood smoke can comprise about a third of upper aerodigestive tract cancers in this region.

5. Conclusion

Indoor air pollution resulting from the use of biomass fuel has the great potential to affect global mortality and morbidity. The amount of fuel burnt individually at the household level may be much less than the amount in use in industries. However, its impact on health is greater due to its ubiquitous and persistent presence in the indoor environment and the greater amount of time spent indoors by humans, especially women and children. This issue is one of the neglected areas of global disease for a large proportion of the world's population. It is in fact not difficult to find a tight relationship between exposure level to biomass fuel smoke and health hazards in both adults and children.

Incomplete combustion of biomass fuel produces high levels of indoor pollutants (e.g., PM, carbon monoxide, sulfur dioxide, etc.). As such, its use can result in devastating effects on human health and diverse potential health risks (such as respiratory tract infections, chronic obstructive lung disease, tuberculosis, asthma, lung cancer, cardiovascular events (e.g., high blood pressure, stroke), cataract, and even exerts adverse effects on neonatal outcome (preterm delivery, low birth weight neonate, infant mortality, etc.). Women exposed to indoor smoke are three times as likely to suffer from COPD, such as chronic bronchitis, than women who cook with electricity, gas, and other cleaner fuels. Exposure to smoke from coal fires doubles the risk of lung cancer. Every year, more than one million people die from lung cancer globally and exposure to biomass fuel smoke is responsible for approximately 1.5% of such deaths. There is consistently strong evidence that exposure to indoor air pollution increases the risk of pneumonia among children under five years and chronic respiratory disease and lung cancer (in relation to coal use) among adults over 30 years old. There is tentative evidence for an association between indoor air pollution and adverse pregnancy outcomes, in particular low birth weight, ischaemic heart disease, nasopharyngeal, and laryngeal cancers.

A wide range of interventions are available to reduce indoor air pollution during cooking activities, for instance, changes in energy technology such as (1) switching from bio-mass fuels to cleaner fuels like kerosene, liquid petroleum gas, biogas, and solar energy, (2) improving the design and construction of locally made traditional stoves by the use of chimney, fume hoods, etc. and (3) changing the living environment such as improving the state of kitchen ventilation and raising awareness among the people about the seriousness of the air pollution associated with cooking. Effective measures addressing the wide range of cooking-related adverse issues via education, economic development, and alternative energies can be highly relevant in solving the potential health problems caused by biomass fuel smoke.

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