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Crop residue burning and air pollution in India: implications for public health and sustainable solutions

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Evidence in Context

- Crop residue burning (CRB) greatly increases air pollution in India, worsening environmental and health crises.
- CRB is associated with various health issues like cardiopulmonary diseases, autoimmune disorders, neurological impairments, and microbiological risks.
- The review highlights the CROP initiative: converting residues to renewable energy, regulation, optimization via advanced technologies, and prevention strategies.
- Mitigating CRB impacts necessitates cooperation between government, healthcare, and environmental groups to protect public health and promote sustainability.

To view Article

Abstract

Background: Crop residue burning (CRB) is a significant contributor to air pollution in many regions worldwide, particularly in India, where it exacerbates an already severe environmental crisis. While the health effects of primary air pollutants are well-documented, detailed investigations focusing on the health implications of CRB remain limited. This review seeks to address this gap by synthesizing existing data to elucidate the specific health impacts of CRB within the Indian context.

Methods: A narrative review was conducted using data from national and international publications. Keywords such as "crop residue burning," "health effects," "air pollution," and "India" were searched on Google Scholar and PubMed. Relevant information from reputable international organizations was also incorporated to complement the analysis.

Results: CRB exposure is associated with diverse health effects across multiple domains, including cardiopulmonary diseases, autoimmune disorders, neurological impairments, and microbiological risks. These effects are intricately linked to broader air pollution dynamics, highlighting the pervasive threat posed by CRB. Addressing this issue requires collaborative action among government agencies, medical professionals, and environmental advocates.

Conclusions: The study underscores the urgent need for a coordinated approach to mitigate CRB's adverse effects on public health and the environment. The proposed CROP (Conversion, Regulation, Optimization, and Prevention) initiative advocates for: Conversion of crop residues into renewable energy; Implementation of a robust regulatory framework.; Optimization of residue management through technologies like the Happy Seeder & Emphasis on prevention strategies. Although challenging, the successful implementation of this initiative offers a cost-effective and sustainable solution tailored to the Indian subcontinent. Legislative measures, medical expertise, and environmental advocacy must converge to tackle this pressing issue and safeguard public health.

Keywords: *Air pollution, crop residue burning, health effects, particulate matter, India*

Introduction

Air pollution is a heterogeneous combination of gaseous material (e.g., $CO2$, $SO2$, CO, $NO3$) and particulate matter (PM), and is an important contributor to the environmental changes worldwide [1]. It shapes health-disease dynamics and is accountable for roughly 7 million all - cause preventable deaths and a global economy burden estimated at 225 billion USD annually - 18 times more than the global burden for tuberculosis [2-5].

The movement and extent of penetration of particulate matter (PM) into the respiratory and circulatory systems are influenced by their size categories. Larger particles, such as PM10, predominantly impact the upper respiratory tract, whereas PM2.5 can infiltrate both the upper and lower respiratory tracts and enter the circulatory system, directly affecting health and increasing the risk of diseases. The ability of PM to carry harmful substances into the lungs is determined by factors such as particle density, size, shape, airway structure, and breathing patterns. Recent studies highlight that atmospheric PM with a diameter of less than 2.5 micrometers (PM2.5) is a critical environmental pollutant and the most significant contributor to the global disease burden. In urban areas worldwide, premature deaths linked to PM2.5 exposure range from 3 to 125 per 100,000 people [2-5].

Over half of these deaths are associated with elevated mortality rates from cardiovascular diseases (CVDs), including ischemic heart disease, cardiac arrhythmias, heart failure, and hypertension. Prolonged exposure to PM2.5 intensifies these risks, especially among vulnerable groups such as those with pre-existing conditions (e.g., diabetes mellitus, asthma, chronic obstructive pulmonary disease etc.), low-income communities, racial and ethnic minorities, and older adults [3-6]. This is particularly alarming, as only 8% of the world's 250 largest cities have population-weighted average PM2.5 concentrations that meet the World Health Organization's (WHO) recommended annual guidelines [1-6].

Air pollution stems from both natural sources (e.g., volcanoes, wildfires) and anthropogenic activities (e.g., fuel combustion, industrial processes, power generation, and agriculture). The latter is far more dominant due to its connection to economic globalization and industrialization [1,6]. CRB, the practice of incinerating agricultural waste to clear fields for the next crop cycle [7], contributes significantly to air pollution. Its impact varies by season, location, and agricultural practices and has been extensively documented in Southeast Asia [8]. India, as the world's second-largest agrarian economy, generates substantial agricultural waste, much of which is routinely burned [9].

While extensive research has explored the harmful effects of air pollution, a detailed analysis of the health impacts specifically attributable to CRB, along with potential solutions, remains limited. This review emphasizes the significance of CRB as a major contributor to air pollution, aiming to inform policy-making in India and enhance sustainability and child flourishing indices for future generations.

Methods

To perform this narrative review, we leaned on published national and international data to individualize the health implications of CRB in India. The terms "crop residue burning", "health effects", "air pollution", "India", or any combination of them, were entered into Google Scholar and PubMed. Selected data coming from renowned international organizations was also utilized to complement the analysis.

Observations and Discussion

CRB in India and the related Health outcomes

CRB Situation in India

India contributes to 3.36% of the world's total GDP and 18% of it comes from agriculture. This sector is the backbone of Indian economy as it employs half of the country's body of work [10-12]. The productive nature of agriculture carries tremendous amounts of crop residues (~500 million tons (MT)/year), primarily from rice, wheat, maize, millet and sugarcane [9].

Agricultural residues are rich in minerals (e.g., zinc, copper, iron) and organic matter, that can aid in enhancing land fertility. It can also be converted into alternative energy (e.g., biofuel), and cattle fodder as it improves its overall health and milk production [13,14]. Nonetheless, CRB is seen as a more convenient approach than proper stubble management, as the latter can be expensive and time-consuming [15]. Approximately 25% of agricultural waste is burned to clear fields for the subsequent cereal crop, a practice particularly prevalent in Uttar Pradesh (~72.02 MT/year), Punjab (~45.58 MT/year) and Haryana (~24.73 MT/year) in Northwestern India (Figure 1) [8,16].

CRB is partially responsible for exposing more than a billion people to exceeding PM2.5 concentrations and has risen air pollution as the second-highest health risk factor in India. In 2017, the country also contributed to ~26% of the global air pollution-attributable Disability-Adjusted Life Year [17,18]. CRB also has detrimental effects on both environmental and economic scales. The process of burning eliminates beneficial microorganisms, modifies soil characteristics, and leads to the depletion of essential nutrients. For instance, burning one ton of rice straw can result in the loss of up to 25 kg of potassium, 5.5 kg of nitrogen, and 2.3 kg of phosphorus. Furthermore, CRB is a significant source of primary air pollutants, including PM2.5, PM10, nitrogen dioxide (NO2), and sulfur dioxide (SO2) [13,19]. Economically, CRB contributes to substantial losses, with estimates suggesting an annual cost of approximately 300 million USD in India alone [20].

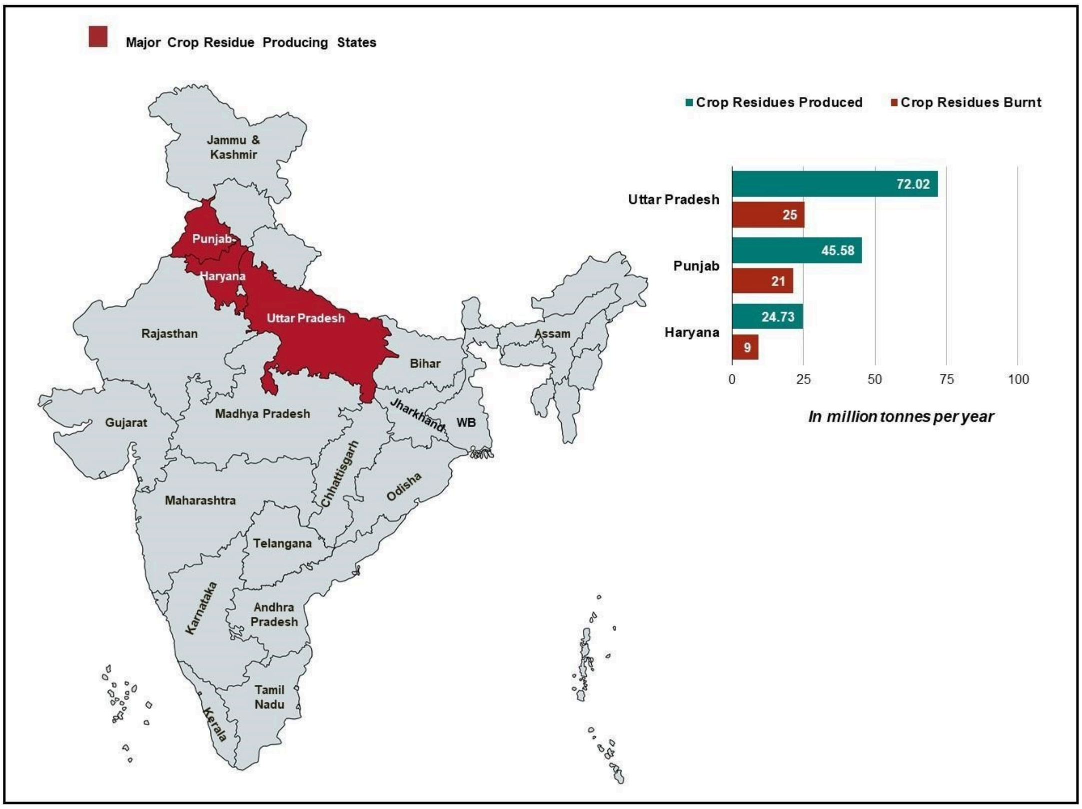

Figure 1: Major crop residue producing States in India

CRB and Health

CRB plays a significant role in exacerbating air pollution, which negatively impacts various physiological systems. The respiratory and cardiovascular systems are particularly affected, as inhaled pollutants—such as particulate matter, sulfur dioxide, ozone, and nitrogen oxides—can trigger conditions like bronchitis, asthma, and an increased risk of cardiovascular diseases.*3.2.1. Cardiovascular System*

Based on epidemiological and selected experimental studies, air pollution exposure might be associated with cardiovascular effects including increased overall cardiovascular mortality, hospital admissions [21-25], and daily outpatient visits [26]. Other pathological conditions include: ischemic heart disease [27,28], heart failure [29], arrhythmias [30], stroke [31], and hypertension [32-33]. Pollution acts not as an independent risk factor for cardiovascular diseases but also acts as an effect modifier for other cardiovascular risk factors [34]. Fine particle air pollution may increase the risk of cardiovascular illnesses through a number of mechanisms, including: a rise in mean resting arterial blood pressure brought on by an increase in sympathetic tone and/or an alteration of the baseline systemic vascular tone. intravascular thrombosis is made more likely by changes in endothelial function and plasma viscosity. the beginning and development of atherosclerosis.

Respiratory System

Polluted air may also be linked with multiple respiratory effects, such as increased incidence of

Chronic cough [35], asthma [36,37], and COPD [38-40], although data seems inconclusive [41]. Gupta et al. examined three strategically selected locations in India, each characterized by varying levels of air pollution. Data on the respiratory health of children were gathered across three distinct timeframes—before, during, and after crop-burning periods. The results indicated a marked increase in respiratory symptoms and a decline in lung function during the crop-burning period, with the severity of these effects varying according to the level of air pollution in each location [42]. Crop residue burning has been shown to have significant adverse effects on local populations—farm households frequently report symptoms such as coughing, eye irritation, headaches, nausea, skin discomfort, and respiratory allergies. Additionally, milder effects, including blurred vision, bronchial infections, dizziness, asthma, and fatigue, have been observed. These findings align with previous studies and publications that highlight the broad health impacts of crop residue burning on affected households. In the northwestern region of India, rising pollution from crop residue burning has been linked to approximately 7,350–16,200 premature deaths and 6 million asthma episodes annually in Delhi [43]. The impact of agricultural crop residue burning (ACRB) on pulmonary function tests (PFTs) was also investigated in a study conducted between August 2008 and July 2009. This study involved 40 healthy participants, comprising children aged 10 to 13 years and young adults aged 20 to 35 years, and provided further evidence of the deleterious effects of ACRB on respiratory health [44]. The study found a significant increase in the concentration levels of SPM, PM10, and PM2.5 in the ambient air of Sidhuwal village. Smaller particulate matter (PM2.5 and PM10) significantly impacted PFTs, highlighting the serious environmental health risks posed by ACRB, with children being more sensitive to air pollution.

Other health impacts of Air pollution

Air pollution has also been linked to neurotoxicity, manifesting as neuroinflammation and myelin damage, which can exacerbate neurodegenerative diseases including but not limited to Parkinson's, Alzheimer's, and multiple sclerosis [45-50]. Additionally, carcinogenesis associated with air pollution has been documented in various malignancies, including hematologic, lung, breast, liver, and bladder cancers [51-55], contributing to the rising incidence of cancer in India [56]. Other conditions tied to air pollution include skin aging and skin cancer [57], rheumatic diseases [58-60], endocrine disorders [61], alterations in the microbiome [62,63], and elevated liver enzymes in newborns [64].

A correlation has been observed between lung cancer incidence rates (LCIRs) and exposure to ambient benzo[a]pyrene (BaP) concentrations in India [65]. A study utilizing data on modeled inhalation exposure to BaP concentrations compared these with LCIRs reported by the Indian Council of Medical Research. The findings revealed a statistically significant correlation between BaP exposure and lung cancer incidence rates among non-smokers, suggesting that BaP contamination is a critical factor in non-smoker lung cancer cases in India. The study also compared death rates from tracheal, bronchus, and lung cancer with lung cancer incidence rates across 13 Indian states, finding a strong correlation between the two. This indicates that death rates from these cancers can serve as a proxy for evaluating the association between lung cancer risk and modeled BaP exposure. Both the incremental lifetime cancer risk (ILCR) and death rates from tracheal, bronchus, and lung cancer in India increased from 1990 to 2014 [65].

The pathogenesis of health consequences due to air pollution remains unclear, but it is believed to involve the penetration of PM2.5 and PM10 through lung alveoli into systemic circulation [66]. These particulate matters (PM) trigger a systemic inflammatory state, which is responsible for extrapulmonary toxicity [67] (Figure 2). While most evidence focuses on general air pollution, the outcomes of crop residue burning (CRB) are extrapolated, as CRB generates exceptionally high concentrations of primary air pollutants [19].

Proposed Solutions

The approach to the underlines problem required a multipronged and collaborative approach:

Solutions and alternatives for CRB

The CROP initiative (Table 1) is a comprehensive, multipurpose and pragmatic solution aimed at alleviating the health and economic burden carried by CRB in India. Cultural, legal, economic, environmental, political, and health concerns were considered whilst contemplating this alternative. It is not intended to be sequential; rather all solutions are intertwined and should be addressed simultaneously.

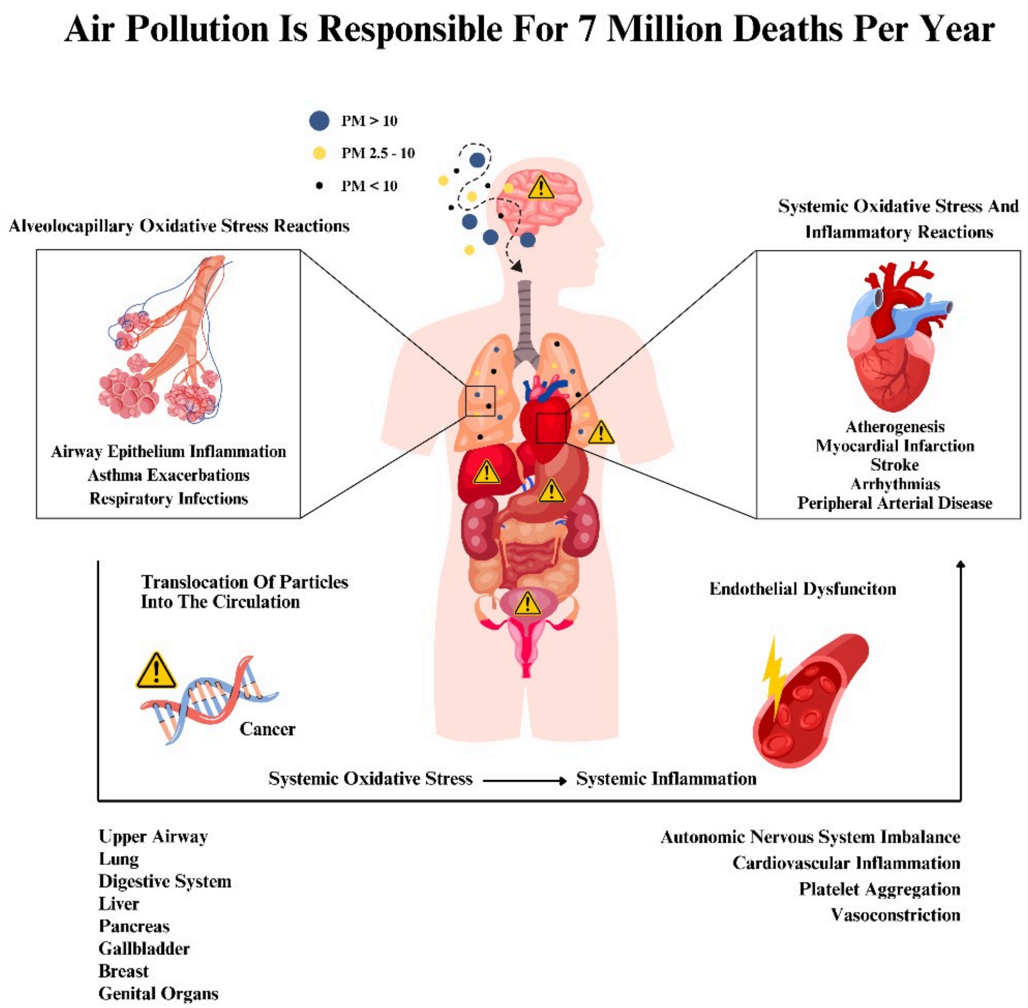

Figure 2: Health effects associated with CRB

Alternative energy is a valuable source and it correlates with a country's economic growth [68]. Crop residues contain significant amounts of organic matter, which can be repurposed into alternative energy sources such as biochar or biofuel—both of which produce lower emissions compared to diesel [69–72]. Furthermore, anaerobic microbes have the potential to convert biomass into high-energy gases, providing a sustainable form of renewable energy [73]. Regarding regulatory actions, several legal efforts have been implemented in India [74]; yet, the situation continues to deteriorate. Both the legality and surveillance systems need to be reviewed and strengthened [75]. This might be achieved with a special body controlled by the Ministry of Agriculture. Optimization of in situ crop waste management is arguably the most impactful action. Because transportation and surveillance systems can be expensive and time-consuming, automated processing (e.g., Happy Seeder) is preferred over manual labor [9,20]. The Happy Seeder, a machine that cuts and lifts straw, whilst sowing the crop directly into the soil has been proven as a cost-effective method with an ideal environmental, economic and agricultural profile; as it improves air quality and soil properties. Unfortunately, this technology is not universally available due to economic and implementation barriers [14,76,77].

Health Prevention

Solutions aimed at prevention are also necessary to reduce further exposure. Susceptible individuals should be educated about the health effects and possible alternatives via social media, schools, and conventional advertisement. To address this issue, it is crucial for all stakeholders—including public and private entities, policymakers, community leaders, physicians, and farmers, among others—to collaborate. Immediate protective measures should focus on minimizing outdoor

Activities during periods of high pollution, safeguarding indoor spaces by keeping windows closed, and employing indoor air purification systems to reduce exposure.

Table 1: The CROP initiative

Action	Description
Conversion	Transform crop residues into valuable alternatives, such as biofuels, biogas via anaerobic digestion, or biochar, reducing open burning and promoting renewable energy.
Regulation	Develop and enforce comprehensive legal frameworks supported by robust monitoring bodies to regulate and ensure sustainable crop residue management practices.
Optimization	Enhance in situ crop residue management through advanced technologies, such as the Happy Seeder, for efficient soil integration and reduced environmental impact.
Prevention	Implement primary and tertiary prevention strategies to minimize CRB exposure by increasing awareness, promoting community-level alternatives, and improving public health responses.

The term "anaerobic digestion" refers to the process of breaking down biodegradable materials in the absence of oxygen to produce biogas. "Biofuel" is a type of fuel derived from renewable biological sources, such as plant materials. "In situ" refers to the management of crop residues without removing them from the field. "Happy Seeder" is a type of machinery used for in situ management of crop residues.

Additionally, primary and secondary preventive measures should be integrated into non-communicable disease national programs [78]. In our recent article, we attempted to add awareness emphasizing the overlooked threat of pollution as a formidable risk factor for cardiovascular and cerebrovascular diseases. While traditional risk factors like smoking, diabetes, hypertension, and hyperlipidemia have been the focus, we argued that pollution's cumulative impact surpasses them, affecting entire populations. The call to action urges a recalibration of our understanding, with the World Health Organization (WHO) urged to prioritize pollution in global health initiatives. Solutions involve dismantling the current paradigm, implementing stringent measures to reduce pollution, investing in sustainable technologies, and adopting green urban planning [79].

Challenges and future direction

In implementing the CROP initiative, the authors recognize the vast challenges in India that may prevent proper execution of these recommendations. India's vibrant democracy creates diverse stakeholders and conflicting interests that may impair policy-making. The powerful agrarian lobby can be expected to obstruct forced mandates and obtaining broad consent of this faction can be cumbersome. Considering the vast cost-effective benefits, it may be advisable for the central and state governments to fund these and similar initiatives.

Conclusions

CRB in India is a significant public health concern at local, regional, and international levels. The large-scale burning of crop residues has alarming health implications, particularly due to air pollution. The most notable effects are cardiopulmonary, including increased cardiovascular mortality, coronary artery disease, heart failure, stroke, COPD, and asthma. Other health issues such as rheumatism, malignancies, neurotoxicity, and microbiota disruption have also been linked to polluted air, highlighting the consequences of mismanaged crop residue burning. The CROP initiative is a comprehensive and cost-effective solution. Simultaneous implementation of its four dimensions (conversion, regulation, optimization and prevention) is encouraged and is expected to alleviate CRB in India. The Happy Seeder alternative may be the most pragmatic solution. While multiple barriers may arise with this initiative, addressing them promptly is essential to prevent future disabilities and mitigate the economic burden. The authors emphasize the critical need to recognize pollution as a significant threat and advocate for a comprehensive, multi-faceted approach to avert an impending public health crisis. We underline the importance of global collaboration, policy changes, and a shift toward a future where clean air becomes a fundamental right for all, envisioning a revitalized world free from the silent suffocation of pollution-induced health crises. Controlling the CRB is an integral step towards not only a better environment but better health. The authors can only hope that more research is done in this area to pivot the course of this ongoing situation.

Abbreviations

ACRB: Agricultural crop residue burning

CVDs: Cardiovascular diseases

CRB: Crop residue burning

CROP: Conversion, Regulation, Optimization, and Prevention

LCIRs: Lung cancer incidence rates

Supporting information: None

Ethical Considerations: Not applicable

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