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Review Article

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# Impact of cotton dust, endotoxin exposure, and other occupational health risk due to indoor pollutants on textile industry workers in low and middle-income countries

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**ABSTRACT**

The textile industry consists of several units that engage different processes namely ginning, spinning, weaving, dyeing, printing, and several other processes which required for converting raw cotton fiber into finished fabrics. Exposure to cotton dust, endotoxin, chemicals, noise, and musculoskeletal disorders causes several health-related hazards to textile workers. This review article aims to study the health issues due to various risk factors associated with the working environment in detail and its impacts on workers' health. This review article also reports dust and endotoxin concentrations in indoor environments of textile industries, as well as discusses the association between workplace exposure to cotton dust, endotoxin, and the prevalence of respiratory disorders. In this review, the focus is also given to the prevalence of indoor pollutants like Particulate Matter (PM), Carbon dioxide ($CO_2$), Carbon monoxide (CO), and Volatile Organic Compounds (VOCs), Formaldehyde (HCHO) in the workplace and its effects on human health. The study expands to other aspects that influence human comfort and health during working hours like occupational noise, musculoskeletal disorders, and eyesight problems. In addition, the advanced technologies for monitoring indoor air quality for control and reduction of pollutants indoor environment the current regulatory limits of cotton dust and indoor pollutants, and suggestions to enhance the occupational safety and health conditions in textile sectors are also pointed out. In conclusion, the current study stresses the need to regulate and apply international standards in the textile sector to prevent short- and long-term occupational illness.

## Review

The textile industry is one of the world's largest industrial sectors, employing anywhere between 20 and 60 million people globally. The textile sector, however, is also responsible for environmental and health risks. Pulmonary ailments, musculoskeletal disorders, noise nuisance, and psychological stress are the most common occupational disorders in the textile industry. The most prevalent health and safety hazards in the textile industry include cotton dust exposure, chemical product exposure, noise exposure, and ergonomics issues. Pulmonary illnesses and disorders continue to be the primary

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cause of occupational impairment and fatality among textile workers [1]. Based on the 2017 report of the World Health Organization (WHO), non-contact diseases are the leading cause of death accounting for 70% of all deaths worldwide. The work-related respiratory disorder accounts for 30% of reported work-related ailments and 10-20 % of deaths across the globe. Workers suffer an estimated 0.386 million fatalities and almost 6.6 million Disability-Adjusted Life Years (DALYs) as a result of occupational airborne particulate matter exposure. Cotton dust and endotoxin exposure are known to occur during the textile and garment manufacturing process. Dust, Suspended Particle Matter (SPM), oil mist, acid vapors, volatile organic compounds, sulfur, and nitrogen oxides are among the indoor pollutants and emissions produced by textile manufacturing processes and operations. Nitrous oxides and sulphur dioxide are produced in the energy production stages; Volatile Organic Compounds (VOCs) are produced in the coating, curing, drying, wastewater treatment, and chemical storage stages; aniline vapors, carrier hydrogen sulphide, and chlorine dioxide are produced in the dyeing and bleaching stages [2-5]. This air pollutant has a significant impact on environmental variables as well as worker health. Long-term exposure to cotton dust causes major chronic respiratory sickness, which has a negative impact on one's quality of life and can even result in death. In the dynamic landscape of the textile industry, the health and well-being of workers hinge on a multitude of influential factors intrinsic to their work environment. These factors, which span from the nature of the processes to the materials employed, play a pivotal role in shaping the overall health of employees. The factors influencing worker's health in the textile industries and the health issues that each of these factors causes are shown briefly in Table 1.

Table 1. The major health risks and issues arise from exposure to the textile industry

| Health Risks | Issues from Exposure |
|---|---|
| Respiratory issues | - Inhalation of dust and fibers leading to respiratory diseases such as pneumoconiosis, asthma, and chronic bronchitis. |
| Skin disorders | - Contact dermatitis due to exposure to chemicals, dyes, and irritants present in textiles. |
| Noise-induced issues | - Hearing loss and other auditory problems due to loud machinery used in the textile industry. |
| Musculoskeletal issues | - Repetitive strain injuries (RSI), musculoskeletal disorders, and back problems caused by repetitive motions, poor ergonomics, and heavy lifting. |
| Chemical exposure | - Exposure to harmful chemicals used in dyeing, finishing, and treatment processes can lead to various health issues, including cancer, reproductive problems, and organ damage. |
| Eye problems | - Eye irritation and damage from exposure to dust, fibers, and chemicals. |
| Mental health issues | - Stress and mental health problems due to long working hours, high-pressure environments, and repetitive tasks. |
| Heart-related illnesses | - Working in hot and humid conditions can lead to heat stress, dehydration, and heat-related illnesses. |
| Ergonomic issues | - Poorly designed workstations and equipment can contribute to musculoskeletal problems and reduce overall worker well-being. |
| Biological hazards | - Exposure to biological agents such as bacteria and fungi, which can lead to infections and respiratory issues. |

Cotton dust is a complex mixture of ingredients that includes ground-up plant materials, cotton fiber, bacteria, fungi, dirt, and insecticides [6, 7]. Cotton dust is tiny dust that is present during the handling and processing of cotton. Cotton dust is known to induce byssinosis, Chronic Obstructive Pulmonary Disease (COPD), Asthma, and lung cancer in both acute and chronic respiratory illnesses[8, 9]. Byssinosis is the most frequent pulmonary illness among textile workers [10, 11]. Byssinosis is a chronic respiratory disease that affects cotton, hemp, and jute workers and is also known as "Monday morning Dyspnea". Endotoxins, which are generated from gram-negative bacteria found in textile dust, are likely to be a major contributor to the pathophysiology of byssinosis, with chronic lung function loss correlating more with endotoxin exposure than with dust exposure. The amount of absorbed endotoxin in bioaerosol is strongly connected to the growth of respiratory disease in cotton and agricultural workers. Endotoxin exposure can cause endothelial cell damage, blood leukocyte influx into the airway, generation of various cytokines, and enhanced synthesis of oxygen metabolites such as Reactive Oxygen Species (ROS), which can cause oxidative lung injury. Several studies have been conducted around the world to determine the health risks associated with personal inhalable dust and endotoxin exposure, as well as the prevalence of lung sickness among textile workers.

Table 2. Diagnosis of various respiratory symptoms in studies concerning nations, methods, sample size, working unit, questionnaire standard, and PFT Parameters

| Country | Methods | Size of sample | Working | Questionnaire Standards | PFT & Parameter | Diagnosis | Ref. |
|---|---|---|---|---|---|---|---|
| Tirupur, India | Selected group Experimental Study | 104 women | Ginning factories | British Medical Research Council | Spirometry & Chest X ray analysis FVC,FEV,PEF,VC , $FEV_1$/FVC% | Byssinosis, Chronic Bronchitis , Asthma | [12] |
| Turkey | Clinical Investigations | 223 persons (182 cases; 41 control) | Cotton Mill Industry | A modified questionnaire No. 684 of WHO | Portable spirometer (MIR Spirobank) | Byssinosis | [13] |
| Northwest Ethiopia | Comparative cross sectional study | 413-276 exposed, 137 unexposed | Textile industry | Modified questionnaire of British medical research council | | Dyspnea, Byssinosis, COPD | [7] |
| Maharashtra, India | | 320 Workers | Ginning industries | Standard respirator medical evaluation questionnaire | Spirometer,FVC,FEV,PEFR,VC, $FEV_1$/FVC% | Byssinosis | [14] |
| Greece | | 443 cotton workers (Smokers, Non-smokers) | Cotton Industry | standardized respiratory symptom questionnaire of the ATS | spirometer (MIR, Spirolab III, Rome, Italy), | Byssinosis, Asthma | [15] |
| El–Beheira Textile Companies, Egypt | cross-sectional descriptive design | 603 workers | Cotton Textile Industry | structured and pre-tested questionnaire | | byssinosis , Dyspnea Allergic rhinitis | [16] |
| North Eastern Thailand | Cross sectional Study | 146 weavers; Age>30 years, 8 h work/day, | Indigo-dyed cotton weavers | self-report questionnaire | chest X-ray via mobile digital radiography | Wheezing, Dyspnea | [17] |
| Ethiopia | comparative cross-sectional study design | 306 cotton dust exposed; 156 bottling factory | Textile Factory | standard American Thoracic Society questionnaire | spirometer (SPIRARE 3 sensor model SPS 320) FVC, $FEV_1$ | chronic respiratory symptoms | [18] |
| Tanzania | descriptive cross sectional study | 325 participants (exposed 164 and control 161) | Cotton textile workers | Modified (BMRC) questionnaire | | Byssinosis | [19] |
| Lahore, Pakistan | Cross-sectional study | 200 subjects, 100 unexposed 100 control groups | Textile industry | A modified, structured questionnaire of the American Thoracic Society (ATS) | Spirometer FVC,FEV, PEFR,VC, $FEV_1$/FVC% | Byssinosis Lung function decline | [20] |

Workers in the textile sector, particularly those involved in dyeing, printing, and finishing, are exposed to a variety of contaminants and chemicals in addition to textile dust. Numerous life-threatening contaminants can infiltrate the air as textiles go through the manufacturing process if they are not handled. Dyes, which contain carcinogenic amines, metals, pentachlorophenol, chlorine bleaching, volatile organic compounds, halogen carriers, free formaldehyde, biocides, fire retardants, and softeners are the principal chemical pollutants as a result of these operations. Too much formaldehyde in textiles can cause respiratory difficulties and skin irritation called contact dermatitis if it comes into touch with the skin. Because the lungs have a large surface area of contact, occupational and environmental chemical hazards are better absorbed into the circulation, resulting in acute or chronic poisonings, acute cardiovascular events, cancers, particularly lung cancer in nonsmokers, or autoimmune diseases [21, 22].

The goal of occupational safety and health is to mitigate both short-term and long-term illness by maintaining a safe working environment. The main aim of this review is to discuss about the association between human exposure to cotton dust, endotoxin, and prevalence of respiratory illness and other health-related issues and to summarize the reported dust and endotoxin concentration in indoor environments and industries. This study also focuses on the indoor pollutants and chemicals generated by textile manufacturing and their effects on human health. Also, other factors which affect human comfort and health are discussed. At the same time, the advanced technologies for monitoring Indoor Air Quality (IAQ) and the current regulatory limits for exposure are also reported.

### *Effects of cotton dust on pulmonary health among textile workers*

Cotton dust exposure is one of the most serious hazards in textile mills. Cotton dust exposure has been linked to respiratory illnesses and a reduction in lung function. The dust particles contain Particulate Matter (PM) of various sizes, which have differing degrees of health impact. $PM_{2.5}$ can penetrate deep into the lungs, irritate and erode the alveolar wall, and impair lung function [23, 24]. Humans experience bronchospasm, shortness of breath, and inflammation of the respiratory passages after inhaling these small dust particles into the lung's alveoli. This ultra-fine particulate matter collected on the surface of the pulmonary endothelium produces pro-inflammatory mediators such as leukotriene B4, interleukin-8, and tumor necrosis factor, which cause inflammation and necrosis in respiratory epithelial cells. This increases airway reactivity, which contributes to respiratory endothelial dysfunction. Ultimately, it results in Chronic Obstructive Pulmonary Disorders like chronic byssinosis, and chronic bronchitis. The prevalence of byssinosis in developing countries can be influenced by various factors, including the level of industrialization, occupational health, and safety standards, and the extent of exposure to cotton or other plant fibers in the workplace. However, byssinosis has been a concern in textile and cotton-processing industries in both developing and developed countries. The developed countries regulate the safety precautions and preventive methods to mitigate the effects of cotton dust exposure in the textile industry. However, developing countries still face additional challenges due to less stringent occupational health and safety regulations, limited access to healthcare, and a lack of awareness about the risks associated with exposure to cotton dust. The prevalence of byssinosis in developing countries is 30% [25, 26], 37% [27], 38% [28], 47.8% [9], 46%[ 29], 34% [11], and 35.6% [8, 30] in Indonesia, Sudan, Egypt, Ethiopia, Myanmar, India and Pakistan. It develops over time as a result of repeated exposure over several years and is largely preventable by dust control measures in the workplace. A Schilling Byssinosis Grading system was later replaced by a more extensive one developed by the WHO in 1983. In short, exposure to cotton dust can cause several respiratory illnesses including both acute and chronic pulmonary disorders among textile workers based on the duration of exposure. So, work-time breaks and switching workers to exposed and unexposed areas in time eventually reduce the risks of developing byssinosis.

### *Respiratory health assessment method*

For the occurrence of Byssinosis and its related factors, most studies used a "questionnaire survey" based on the British Medical Research Council (BMRC), Occupational Safety and Health Organization (OSHO), American Thoracic Society (ATS), and St.George's Respiratory Health Questionnaire (SGRQ). Several studies suggested using Spirometry and Chest X-rays to diagnose pulmonary functions in exposed and control groups to determine Forced Expiratory Volume in the first second ($FEV_1$) and Forced vital capacity [29] ($FEV_1$) to determine the phases of byssinosis. The different method used for assessing the respiratory health of textile workers is shown in Fig. 1. In several investigations, inhalable dust concentrations were evaluated using a dust sampler with a filter and an IAQ (Indoor Air Quality) monitoring system to determine whether it was linked to respiratory illnesses [11]. A vast number of researchers recommended Statistical Packages for Social Sciences (SPSS) for data processing and analysis to discover the individual risk variables linked to the prevalence of lung illnesses among textile workers. Statistical analysis such as the logical regression analysis and chi-square test will be used to assess the relationship between specific risk factors of respiratory illness [31]. Most of the studies used both questionnaire surveys and pulmonary function tests using spirometry to assess the respiratory health of workers which helps to validate the associated pulmonary risk factors among textile workers.

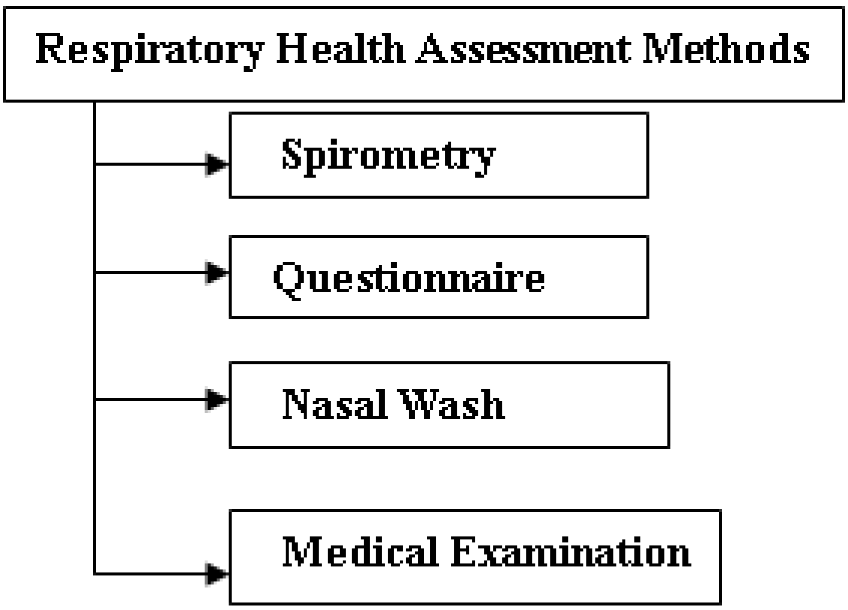


Fig. 1. Different respiratory health assessment methods

***Cotton dust exposure and respiratory outcomes***

Cotton mill workers demonstrate a significant decrease in $FEV_1$, $FEV_1$/FVC, and PEFR as compared to controls [10]. The pulmonary functions are shown by these spirometry indicators, which aid in the diagnosis of respiratory illnesses. According to a study of 290 home-based power loom workers in Madhya Pradesh, 11% of those with Byssinosis-like symptoms also had TB, and 29% were in the early stages of Byssinosis (Grade 0.5) [32]. Several studies on cotton dust exposure and respiratory problems in Ethiopian textile factories were available. In a study of a Northwest Ethiopian textile business, 413 (276 exposed and 137 unexposed) individuals revealed that 47.8% and 15.3% of exposed and control groups, respectively, self-reported respiratory problems [10]. Another Ethiopian study indicated that the exposed and control groups experienced 68.6% and 19.2% respiratory symptoms, respectively, in 166 adults (83 cotton-ginning workers and 83 healthy controls). Cotton yarn workers had reduced FVC, FVC %, $FEV_1$, $FEV_1$/FVC percent, PEFR, and FEF 25-75% when compared to controls [18]. With increasing exposure length, the cotton-ginning employees' Forced Vital Capacity (FVC), Peak Expiratory Flow Rate (PEFR), and forced expiratory volume in 1 second ($FEV_1$) all dropped significantly, and blood tests revealed higher erythrocyte sedimentation rate, eosinophils, and white blood cells when exposure was longer [13]. In a study conducted within Pakistan, 303 grownup male textile workers from 5 mills' spinning and weaving cloth departments revealed a drop in spirometry indices. The amount of cotton dust ($PM_{2.5}$) ranged from 0. 5 to 4 mg/$m^3$, and each mg/$m^3$ multiplies dust concentration is related along with a 5. 4 % reduction in $FEV_1$ [33, 34]. In 2016, Hinson et al. conducted a study in Benin to assess the respiratory health of textile workers. Typically the study included 656 cotton dust-exposed subjects and 113 non-exposed subjects the studies revealed that happen to be exposed to silk cotton dust have bigger respiratory symptoms as compared to those who happen to be not exposed [35, 36]. Recently, Asaad et al undertook research involving 7 textile mills in the particular Karachi region associated with Pakistan where these people determined cotton dust exposures by making use of three different dirt measurement equipment and conducted two experimental works for evaluating personal dust and area dust concentrations [37]. From the previous studies, it is found that high dust concentration is present in the personal breathing zone (IOM=1.07 mg/$m^3$) compared to area dust (Dylos=0.09 mg/$m^3$) at a particular location [37]. So, dust control measures help to prevent the prevalence of Byssinosis. The prevalence of Byssinosis and work-related respiratory symptoms among textile workers has been studied in several countries [34]: the respirable dust concentration was 3.30 mg/$m^3$, and 50.7% of textile workers (207 workers) were exposed to an increased level of respirable dust concentration and 52.7% had reduced lung functions in Myanmar [29]. In Taiwan, 38.5 % of people had deteriorated lung function. The mean value of FVC in the occupational setting in Myanmar is 82.82% [29], Thailand 106.0% [38], Greece 90.6% [39], and Pakistan 90.3% [29, 33]. Meanwhile, the mean value of $FEV_1$ in the exposed groups; Thailand 101%, Myanmar 83.64%, Greece 91.7%, Pakistan 83.63%, Iran 88.8% and Turkey 96.2% [29, 33, 38-41]. Cotton and hemp workers have shown a faster drop in $FEV_1$. Berry et al discovered a faster annual reduction in $FEV_1$ in cotton mill employees compared to synthetic mill workers. Over ten years, Zuskin et al., observed a faster reduction in $FEV_1$ among male cotton textile workers. Beck et al monitored 383 cotton workers and 277 age-matched controls from the general inhabitants for a season and found that cotton workers lately had a quicker lung decline than controls, even in nonsmokers and after retirement. According to previous studies, Indonesia, Thailand, and Sudan showed a low prevalence of byssinosis (i.e., 30% and 37%). A higher prevalence of byssinosis was shown in the textile industries of India, Pakistan, Ethiopia, Benin, Myanmar, and Turkey [42]. Shankar et al., investigated the impact of particulate matter and gaseous pollutants found in the textile sector on respiratory symptoms, and pulmonary function about power loom workers of 97 respondents in Tamil Nadu, India. Their results revealed that regarding the respiratory symptoms, for the previous 12 months, around 30.8% cough was prevalent, 14.9% dry cough, 20.2% phlegm, 22.8% wheezing, 23.6% chest tightness, 7.1% chest discomfort, and 32.4% sneezing. Regarding the lung function of power loom workers, 86.07% of them had restrictive pulmonary abnormality and 13.9% had obstructive lung abnormality, accounting for 81.4% of the decline in lung function [11]. Table 2 shows the diagnosis of various respiratory symptoms in studies concerning nations, methods, sample size, working unit, questionnaire standards, and PFT parameters to find an association between respiratory risk factors.

Breathing difficulties is a common chronic non-communicable pulmonary illness, similar to Byssinosis [34]. According to the World Health Organization, asthma is characterized by typical symptoms of shortness of breath and wheezing. Several nations have already researched the prevalence of work-related asthma among textile workers: Thailand has a 9.1% [34, 38], in Croatia, 0.9 % of women and 1.1% of men workers in the textile industry. In a recently available study conducted in Vietnam, 11.9% had suspected symptoms of asthma, 7.4% were diagnosed with asthma, and 5.3% were clinically diagnosed with cotton dust-related allergic asthma among 1082 textile workers [34, 35]. Several epidemiologic research works have examined typically the link between natural cotton dust exposure and lung cancer, yet findings remain inconsistent [43-45]. The effects of job exposure to cotton dust on lung cancer risk were explored in Lithuania [43]. The epidemiology of the respirator symptoms such as byssinosis, asthma, blood phlegm, bronchitis, cough and wheezing based on the World Health Organization (WHO) Category of Diseases is presented in Table 3.

Table 3. Epidemiology of respiratory system

| Pathology | Epidemiology | Ref. |
|---|---|---|
| Byssinosis | Byssinosis is a respiratory condition caused by extended exposure to non-synthetic raw fabrics during the manufacturing process. Brown lungs illness, Monday fever, and mill fever are all names for cotton worker's lung disease. It has symptoms that are similar to COPD | [18] |
| Asthma | Work-Related Asthma is the most frequent respiratory ailment in the workplace. A detailed occupational history is necessary when it comes to identifying patients. Although asthma can strike anybody at any age, occupational exposures, such as those in the textile industry, are linked to approximately 17% of all adult-onset asthma cases. | [33] |
| Blood phlegm (hemoptysis) | Hemoptysis is a medical condition in which a patient expects to see blood-stained mucus. Hemoptysis accounts for 15 % of all pulmonology encounters, and it's associated to life-threatening medical conditions including lung cancer. | [34] |
| Bronchitis | Inflammation in lungs bronchial airways is mainly due to bronchitis and it is more prevalent in winter when flu is common. Potential causes of bronchitis are smoking, environmental exposure and history of asthma and allergens such as pollen and perfumes can also cause bronchitis. | [35] |
| Cough | Chronic cough is one of the most frequent symptoms of chronic diseases, with chronic cough affecting roughly 12% of the global population on a daily or weekly basis. Chronic cough is linked to both physical and psychological disorders. | [36] |
| Phlegm | Chronic phlegm is a key symptom of respiratory illnesses. A decline in lung function has been associated with the presence of phlegm. The main risk factors for chronic phlegm are smoking tobacco and biomass fuel exposure. | [39] |
| Tuberculosis | Mycobacterium tuberculosis is the causative agent of Tuberculosis and is also known as the "White Plague". | [40] |

Moreover, textile employees who else worked in sections with greater degrees of cotton dust direct exposure, such as ginning, spinning, weaving, blowing, and pressing, had been very likely to have their particular lung functions decreased than those who else worked in different departments. Cotton ginning and spinning, in particular, has been reported to have the highest burden of respiratory illness. The concentration of cotton dust with a particle size associated with 2.5 $mg/m^3$ was higher within the ginning section, according to the study conducted in Ahmedabad, India, elevating the risk associated with developing respiratory signs and symptoms [46]. Direct exposure to dust may cause a reduction in lung function, and pulmonary illnesses caused by occupational exposure are mostly caused by dust inhalation and deposition in the lungs [47]. As a result, textile workers with extended service periods, smoking behaviors, and cotton dust exposure were at a higher risk of developing chronic respiratory health problems, and respiratory symptoms have also been related to dust density and concentrations in the workplace [48]. By a survey involving cotton-ginning employees, 51%-71 % experience chest tightness, 55%-62% expertise chest pain, together with 33%-42 % currently have frequent coughing based on the concentration of exposure. Furthermore, prolonged exposure generates greater levels of erythrocyte sedimentation rate, eosinophils, and white blood cells in the worker. The dust concentration in various sections of the textile industry is shown in Table 4.

The researchers expressed the opinion that the unorganized sectors such as traditional or native-based handloom, power loom, and home-based textile manufacturing have a greater impact on environmental and health hazards when compared to organized sectors. Also, all the recent findings strengthen this opinion. In addition, all the findings of previous studies revealed that Asian and Middle Eastern African countries had more prevalence of respiratory illness associated with cotton dust in the textile industry. Based on the findings of cotton dust concentration in various sections of the textile industry, it can be argued that the spinning and weaving section has been exposed to the highest cotton dust concentration and greater burden of respiratory illness. Overall, long-term cotton dust exposure can cause severe pulmonary illness. So, it is important to implement international standards, and regulating the unorganized sectors may reduce the risks to worker's quality of life. Also, periodical medical examination and use of personal protective equipment like face shields, and mask can minimize the exposure concentration and results in lesser respiratory symptoms.

Table 4. Particulate matter concentration in the various sections of textile industry

| Country | Exposure Time | Dust measurement equipment | Dust Concentration in various sections of textile industry in ($mg/m^3$) | | | | | Ref. |
|---|---|---|---|---|---|---|---|---|
| | | | Ginning | Spinning | Weaving | Pressing | Cleaning | |
| Gondar, Ethiopia | 8 h | AIRVEDA Dust Measuring Equipment | $PM_{2.5}$ - 0.25<br>$PM_{10}$ - 0.82 | - | - | $PM_{2.5}$ - 0.235<br>$PM_{10}$ - 0.580 | $PM_{2.5}$ - 0.224<br>$PM_{10}$ - 0.420 | [18] |
| Maharashtra, India | 8 h | Portable personal dust sampler with glass fiber filter | 2.0 - 6.0 | - | - | 1.2 - 5.0 | - | [13] |
| North Ethiopia | 8 h | Vacuum air Sampler, Millispore plastic cassette sampling head with dust-arresting filters | - | 0.035- 5.23 | 0.23-1.67 | - | 0.32-7.01 | [49] |
| Karachi, Pakistan | 8-12 h | UCB-PATS (University of California, Berkeley-Particle & Temp. Monitoring system | - | 0.5-0.9 | 0.2-0.4 | - | - | [33] |

Table 4 (continued)

| Country | Exposure Time | Dust measurement equipment | Dust Concentration in various sections of textile industry in ($mg/m^3$) | | | | | Ref. |
|---|---|---|---|---|---|---|---|---|
| | | | Ginning | Spinning | Weaving | Pressing | Cleaning | |
| Thamine, Myanmar | 8 h | Air sampling Pump (Aircheck 3000 Deluxe model 210-3311,SKC limited,UK) | - | 4.1 | 2.7 | - | - | [48] |
| Tamil Nadu, India | 24 h | Oizom Polludrone Air Quality Monitoring System | | | $PM_{2.5}$- 3.88<br>$PM_{10}$- 8.86 | | | [11] |

***Effects of endotoxin on pulmonary health among textile workers***

Endotoxins are Gram-negative bacteria lipopolysaccharides found in textile dust that have detrimental effects on the respiratory system and cause chronic loss of lung function [35]. Airborne endotoxins have been linked to an increased prevalence of asthma as well as a worsening of asthma symptoms. The most frequently used and recognized technique for endotoxin quantification in occupational and environmental samples is the chromogen-kinetic Limulus Amoebocyte Lysate (LAL) assay [50]. The particular endotoxin levels within the jute mill's batching, spinning, and weaving cloth areas were 0.22–4.42 µg/m$^3$, 0.04–1. 47 µg/m$^3$ and 0.01–0.07 µg/m$^3$ respectively, which were calculated in Indian natural cotton mills and the results showed that increased exposure to microbial endotoxin in air-borne dust is associated with byssinosis symptoms amongst Indian jute work workers [51]. The endotoxin measurement techniques and exposure range concentrations, pulmonary function test, and respiratory impact on textile workers in various countries are shown in Table 5. According to Farokhi et al., endotoxin-induced respiratory health consequences are not limited to high exposure levels, as respiratory effects have been identified in exposure groups as low as 100 EU/m$^3$ [52]. In a French population-based case–control study, Ben Khedher et al., found an inverse relationship between assumed endotoxin exposure and lung cancer in 2926 patients with clinically confirmed lung cancer and 3555 matched controls [53]. The concentration of airborne endotoxin in the textile industry of Nepal was 86-300 EU/m$^3$ for 114 workers and 26-300 EU/m$^3$ for 938 workers throughout a complete shift. Indoor endotoxin concentrations varied from 0.02 to 8.13 EU/m$^3$ in Taiwanese research [54]. A total of 447 exposed textile personnel and 472 unexposed silk personnel were evaluated in a Chinese study, and recent span exposure to endotoxin (within 5 years) was associated with chronic respiratory symptoms in retirees, quite than cumulative coverage. In line with the findings, the timing of work-related endotoxin exposure may impact the rate of FEV1 decline and the occurrence of respiratory symptoms in textile workers [54]. In two textile companies in Lahore (Pakistan) airborne endotoxin concentrations of 12 -360 EU/m$^3$ were found while comparing 100 textile workers and 100 controls, the group aged 30 to 40 years old had considerably lower force vital capacity and peak expiratory flow characteristics and pulmonary abnormalities [20]. So, it is very clear that Endotoxin has been associated with chronic bronchitis, wheezing, and a decline in lung function. Overall, the garment section in the Ethiopian integrated textile industry showed the least endotoxin concentration about 76 EU/m$^3$, and showed less respiratory symptoms among exposed groups but study time and population are limited. However, based on previous and recent research, it is evident that the presence of gram-negative bacteria lipopolysaccharides in endotoxin can cause several health issues when people are exposed in long term.

Table 5. Different Endotoxin measurement tests and concentration and associated health impacts on textile workers

| Field of work | Country | Study group | Method & pulmonary function test | Endotoxin(ET) Measurement Test | ET exposure range | Ref. |
|---|---|---|---|---|---|---|
| Textile Industry | China | 447 cotton textile workers (exposed); 472 unexposed silk workers | Questionnaire (BMRC), Spirometry | Chromogen-kinetic Limulus Amoebocyte Lysate (LAL) Test | 40-5800 EU/m$^3$ | [54] |
| Textile Industry | Germany | 150 Cotton spinning mill workers | Questionnaire survey , Spirometry | Personal sampler with glass fiber filter. | 134-823 EU/m$^3$ | [55] |
| Integrated Textile Factory | Ethiopia | 630 workers from various sections of Textile Factory | Questionnaire Survey, Spirometry | Kinetic-chromogen Limulus Amoebocyte Lysate Test | 530 EU/m$^3$ | [31] |
| Textile Industry | Pakistan | 100 textile workers and 100 control groups from same industry. | Questionnaire Survey, Spirometry | Chromogen-kinetic Limulus Amoebocyte Lysate (LAL) Test | 12-360EU/m$^3$ | [20] |
| Textile Industry | Nepal | 114 (2011) and 938 (2015) textile workers | | Chromogen-kinetic Limulus Amoebocyte Lysate (LAL) Test | 86-300EU/m$^3$ 26-300EU/m$^3$ | [56, 57] |

Several pollutants and chemicals found in indoor air have been linked to poor indoor air quality and human health. The most frequent indoor air pollutants include NOx, volatile and semi-Volatile Organic Compounds (VOCs), $SO_2$, $O_3$, CO, PM, radon, toxic metals, and microorganisms. These hazardous wastes have the potential to cause diseases and serious health issues in humans, such as respiratory and cardiovascular ailments. When compared to organized sectors, unorganized sectors such as handloom, power loom, and home-based textile manufacturing pose greater environmental and health dangers. Chemicals are more likely to cause a variety of ailments, and workers in the dyeing, printing, and finishing industries are more susceptible. Various harmful compounds, such as chemicals and dyes, are commonly used in factories. These compounds are mostly employed in garment color and design. These, on the other hand, are extremely hazardous to the skin and other bodily parts [58].

***Particulate matters emission***

Particulate Matter (PM) is a major pollutant which is a mixture of tiny solid particles and liquid droplets suspended in the air. Mainly because individuals spend 80–90% of their very own time indoors and even indoor pollutant degrees are often more than outside pollutant degrees, assessing the unfavorable health effects regarding indoor air PM exposure at residences and work areas is important [59]. PM can be subdivided based on size into coarse ($PM_{10}$–$PM_{2.5}$), fine ($PM_{2.5}$–$PM_{0.1}$), and ultrafine ($PM_{0.1}$). These particles, when breathed, can harm the heart and lungs, resulting in catastrophic health consequences. Various research groups have undertaken numerous studies on PM exposures all over the world. According to epidemiological evidence, exposure to PM is associated with acute and serious adverse health outcomes such as decline in lung function and asthma abnormalities, respiratory and cardiovascular diagnosis-related hospital admissions, fatality, and morbidity, particularly among the elderly and people with a history of respiratory symptoms, as well as the development of heart diseases. Thus, the particulate matter has adverse impacts on pulmonary and cardiovascular functions.

### *PM and its effects on pulmonary functions*

The concentrations of particulate matter with an aerodynamic diameter of 2.5 µm ($PM_{2.5}$) in the textile sector ranged from 0.5 to 4 mg/m$^3$, and every mg/m$^3$ increase in dust concentration was associated with a 5.4% decrease in $FEV_1$ [33, 34]. An observational research in Northeast Scotland found that $PM_{2.5}$ exposure caused serious health consequences for 148 people [60]. Another study assessed $PM_{2.5}$ concentrations in the cotton ginning industry among 320 workers using portable dust samplers, and the results revealed that ginning workers have a significant prevalence of respiratory impairment or allergies [13]. In a study of 443 employees, both smokers and non-smokers, the effects of $PM_{10}$ on lung function were explored, and the data revealed that exposure to $PM_{10}$ might be one risk factor for reduced lung function. ETS (Environmental Tobacco Smoke) is a key cause of elevated $PM_{2.5}$ levels indoors. Workers in the textile industry who smoked had a higher risk of respiratory problems. According to continental exposure assessments, Asia has the highest rate of lung cancer linked to $PM_{2.5}$, followed by North America and Europe [61]. A very recent study results show, there is a significant association between $PM_{2.5}$ and $PM_{10}$ concentration and abnormality of FVC% and $FEV_1$% among textile power loom workers [11]. In summary, $PM_{2.5}$ and $PM_{10}$ are the deadly factors causing Chronic Obstructive Pulmonary Diseases, Asthma, and Chronic Bronchitis. In addition, Tobacco smoking elevates the level of $PM_{2.5}$ emission in the indoor environment resulting in adverse health effects among textile workers.

### *Effects of PM on cardiovascular functions*

Particulate matter influences both pulmonary inflammation and blood coagulation. Pollutant that irritates the lungs causes blood clotting in blood vessels, culminating in angina or myocardial infarction. Several investigations have found a direct association between cardiovascular disease and air pollution. In epidemiological investigations of air pollution, the increased risks of cardiovascular events have been associated with short and long-term exposures to particulate matter [62, 63]. Changes in blood pressure, inflammation, and blood coagulation may be caused by inhaling small particles, however, pathogenetic routes are uncertain [63, 64]. PM exposure is associated with increased oxidative stress, which can contribute to the development and progression of cardiovascular diseases and is also linked to endothelial dysfunction, affecting the ability of blood vessels to regulate blood flow and maintain vascular tone[65, 66]. Long-term exposure to elevated PM concentrations is associated with an increased risk of hypertension [67]. Investigation into the impact of particulate matter on mortality has found significant risk in male and female cohorts in the United States, particularly in postmenopausal women[68]. Ischemic heart disease mortality was shown to be higher among textile workers in the United Kingdom, particularly weavers and spinners, as well as among textile workers in Sweden [69]. Workers in the textile business who are self-employed had a higher rate of ischemic heart disease hospitalization. The short-term effects of particulate matter on stroke have been studied in 26 significant Chinese cities, and $PM_{2.5}$ and $PM_{10}$ were found to be strongly linked to an elevated risk of ischemic stroke [61]. Overall, the results of previous studies revealed that ischemic heart disease or stroke is the major cardiovascular disease that occurs due to long-term exposure to PM rather than changes in blood pressure among workers in textile-related manufacturing sectors. In addition, particulate emission may severe cardiovascular issues in textile workers who already with of symptoms or diagnosis.

### *Emission of carbon dioxide in textiles*

According to a preliminary approximation, textile industries release one ton of carbon dioxide for every 19.8 tons of total carbon dioxide released. The primary source of (Greenhouse Gases)

GHGs in the textile sector is on-site fossil fuel combustion, whereas indirect emissions are caused by the purchase and usage of electricity [70]. Natural gas is a main fossil fuel in the textile industry, and it is used to heat boilers so that steam may be used to dry the cloth. According to some assessments, the garment sector is the second-largest industrial polluter, accounting for 10% of world carbon emissions [71]. The emission of carbon dioxide causes headaches, nausea, and other health-related problems [72].

### *Effects of $CO_2$ on human health*

Environmentally significant $CO_2$ rises (5,000 ppm) may cause direct dangers to human health, according to growing data. Carbon dioxide has the effect of lowering the pH of blood serum, resulting in acidosis. Acidosis has two minor side effects: restlessness and moderate hypertension. $CO_2$ exposure at high levels between 2000ppm and 3000ppm has been linked to reduced cognitive performance and productivity, inflammation, kidney calcification, bone demineralization, oxidative stress, and endothelial dysfunction, as well as cardiovascular effects such as increased heart rate and blood pressure. All these recent findings clearly showed that $CO_2$ exposure not only has a negative impact on the environment but also it causes greater adverse effects on human health. Although the textile industry is responsible for 10% of global $CO_2$ emissions there is limited research to evaluate the association between $CO_2$ exposure and respiratory risk factors among textile workers.

### *Volatile organic compounds (VOCs) in textiles*

VOCs (volatile organic compounds) are carbon-based compounds that can vaporize at low or room temperatures. VOCs are formed in the textile manufacturing industry during coating, curing, drying, dyeing, wastewater treatment, and chemical storage. Volatile Organic Compounds (VOCs) are emitted from various processes within the textile industry. The concentrations of VOCs can vary depending on factors such as the specific processes involved, the types of materials used, and the technology and equipment in place. Textiles and garments have long been treated with HCHO (Formaldehyde)-releasing chemicals and adhesives to improve anti-creasing properties [73]. HCHO is utilized to improve wrinkle and flame tolerance, dye and ink penetration, and emulsifier and whitening agent reliability in fabric polishing.

### *Effects of HCHO on human health*

Formaldehyde may be inhaled, and it can also be ingested through the skin. HCHO has been classed as human carcinogenic by the International Agency for Research on Cancer (IARC) based on epidemiological evidence. Skin inflammation, breathing issues, coughing, and burning sensations in the eyes, nose, and throat are all possible side effects of HCHO indoor exposure [74]. Brain cancer and leukemia can be caused by long-term exposure to these substances [75]. The impact of VOC and HCHO exposure on textile workers of different countries concerning study design, worker's gender, size of exposed and control groups, cancer type and diagnosis, and main results of finding is shown in Table 6. Meyers et al. [76]investigated the association between formaldehyde and leukemia among 11,043 garment workers in the United States. Checkoway et al. [77], investigated associations with occupational exposures potentially related to lung cancer among women textile workers in Shanghai, China. As a result, it was found that exposure to formaldehyde may have increased lung cancer risks among textile workers. Wong et al investigated the relationship between occupational exposure and the risk of thyroid cancer among textile workers of Chinese women, and their findings imply that thyroid cancer and long-term FA exposure may be interrelated [78]. Overall, it is clear that long-term HCHO exposure promotes cancer in humans. All these recent findings showed that formaldehyde exposure could cause carcinogenic effects and potentially related to the promoting of lung cancer among textile workers.

Table 6. Exposure of VOC and HCHO and diagnosis of textile worker's health

| Country | Methods | Sample size | Working area | Exposure evaluation | Indoor Carcinogens | Diagnosis & Cancer Type | Ref. |
|---|---|---|---|---|---|---|---|
| USA | Comparative cross sectional study | 201 cases, 203 controls | Various (Including garments) | Job exposure matrix | HCHO | Non-Hodgkin lymphoma (NHL) | [79] |
| China | Case control | 2 cases, 11 non-cases | Textile Industries | Historical measurements data | VOC, HCHO | Thyroid cancer | [78] |
| China | Case control | 2 cases, 11 non-cases | Textile industries | Job exposure Matrix, Spirometry | HCHO | Lung cancer | [77] |
| USA | Case control | 7345 Workers | Textile industries & Various | Occupational history data | VOC, HCHO | Nasopharyngeal cancer | [80] |
| USA | Case control | 11039 Workers | Garment factory | Personal sampling among workers | HCHO | All cancers | [81] |

***Musculoskeletal disorders among textile workers***

Work Musculo Skeletal Disorders (WMSDs) are injuries to the muscles, tendons, or nerves that are painful or disabled and are caused or aggravated by work. [82]. WMSDs are commonly caused by awkward postures, prolonged static tasks, and repetitive motions. Furthermore, job dissatisfaction, workplace stress, and time constraints are also key psychosocial aspects associated with WMSDs. Textile workers suffer from musculoskeletal ailments such as neck pain, back pain, knee pain, shoulder fatigue, and leg discomfort as a result of repetitive tasks and abnormal postures. In a research of 232 Ready Made Garment (RMG) workers in Bangladesh, the prevalence of WMSDs in nine body areas was evaluated, as well as an ergonomic evaluation of their exposure to risk factors for the development of WMSDs. In the same survey, 46 female respondents (24.7 %) and 44 female respondents (44.7 %) experienced lower back pain, whereas 10 male respondents (21.7 %) claimed neck pain and six reported knee discomfort (13 % ) [83]. Another research looked at the prevalence of musculoskeletal complaints among garment workers in Kandal Province, Cambodia, and discovered that 92% of them experienced musculoskeletal disorders in at least one body region [84]. Ergonomic interventions in terms of working space, workers' sitting/standing posture, seat and hand position during work, and the work-rest cycle to address musculoskeletal risk factors to be addressed in the textile industry.

***Noise exposure in textile workers***

Most textile manufacturing units, particularly those in developing nations shown to have high levels of noise exposure, and noise level in different textile industry parts is shown in Table 7. Long-term exposure to abnormal noise levels has been shown to induce eardrum destruction and hearing damage [85, 86]. As a result of continual noise exposure, other concerns such as tiredness, absenteeism, irritation, anxiety, and lower productivity, changes in heart rate and blood pressure, and sleep disturbances have been documented. Noise sensitivity had the greatest effect on increasing occupational stress and job satisfaction [87]. According to research by Ruikar et al, 76.6 % of employees at textile mills in Nagpur were at risk of acquiring noise-induced hearing loss. According to other studies, 21.3 % and 49.5 % of workers suffer from noise-induced hearing loss. Noise levels above 90 decibels have a negative impact on workers' health and psychological well-being and also suffer from acute hearing loss [88]. The degree of damage to hearing ability is dependent on the length of employment, i.e., employees who have worked for more than 16 years may experience hearing loss even at low frequencies, whereas office workers may experience little or no effect [89]. High noise levels have an adverse impact on worker performance, as well as agitation, persistent tiredness, disorientation, headaches, and other nervous and psychological illnesses. Machinery should be properly maintained to reduce noise levels, and workers should be given earplugs if the noise level exceeds. The noise level should be maintained below 90 dB to minimize the effects of physical and psychological disorders related to long-term exposure to high noise levels.

Table 7. Noise level in different textile industry parts

| Spinning Mill | Weaving Mill | Knitting Mill | Dyeing & finishing | Cutting & sewing |
|---|---|---|---|---|
| Carding machine: 80-95 dB | Shuttle loom: 90-105 dB | Circular knitting machine: 80-95 dB | Jet dyeing machine: 85-100 dB | Cutting machine: 80-95 dB |
| Ring spinning frame: 85-100 dB | Air jet loom: 80-100 dB | Flat knitting machine: 75-90 dB | Calender machine: 80-95 dB | Sewing machine: 75-90 dB |
| Roving frame: 80-95 dB | Rapier loom: 75-95 dB | | Stenter machine: 85-100 dB | |

It's important to note that prolonged exposure to high noise levels can have adverse effects on the hearing health of workers. Therefore, industrial settings often implement noise control measures, such as using ear protection devices, enclosing noisy machinery, and employing engineering controls to reduce noise at the source. Regular monitoring and assessment of noise levels are crucial to maintaining a safe and healthy work environment in the textile industry.

### *Eyesight problems among textile workers*

The constant visual attention affects worker's eyes drastically, in addition to the effects of work on the body, muscles, and repetitive work [90]. Watery eyes, cataracts, straining, and eye swelling were also observed by several textile workers, and observations at work imply that most sheds lack uniform and enough lighting. Correct lighting and typical work breaks prevent eye muscle fatigue, and redesigning job tables to enable work to get completed in the typical attention range gives workers more comfort and increases job quality and productivity. Proper illumination should be provided at the workplace to reduce eye strain and the average illumination level ranges from 600-800 lux. However, workers must be free of glare and excessive contrast. Otherwise, it may lead to eyesight problems or eye-related illness and ultimately result in less productivity.

### *Causes of the pollutants and methods for reducing exposure in textile industry*

Textile processes generate airborne particulate matter, including fibers and dust, which can contribute to respiratory issues among workers. The use of various chemicals in dyeing, finishing, and treatment processes contributes to air and water pollution. Chemicals such as dyes, bleaching agents, and finishing agents may contain hazardous substances which affect workers who are directly exposed to those substances. Implementing enclosed processes and effective ventilation systems can help control the release of airborne pollutants, protecting both workers and the surrounding environment [11]. Implementing green chemistry principles involves using environmentally friendly chemicals, processes, and materials in textile manufacturing. This can minimize the generation of hazardous pollutants.

### *Current standards limits for cotton dust and indoor air pollutants*

National and international organizations give several guidelines and regulations to limit the impact of indoor air pollution on human health. Most countries standards for estimating and evaluating indoor air quality and exposure emission limit in textile industry were developed by the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH), and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). OSHA established a standard guideline for cotton dust exposure in the workplace in 1978, which was revised in 1985 and 2001. The standard established a Permissible Exposure Limit (PEL) for cotton dust in all-cotton industrial processes. The OSHO permissible limit of cotton dust in various sections of the textile industry is shown in Table 8. According to the findings, there are few regulations or guidelines for monitoring IAQ in non-industrial buildings. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), for example, provides guidelines for thermal comfort and air exchange rates in industrial buildings including textile industries.

Table 8. OSHO permissible exposure limit for cotton dust in textile industry

| Standard | Production stage | Permissible limit in μg/m$^3$ |
|---|---|---|
| | Yarn production | 200 |
| OSHO PEL | Spinning | 200 |
| | Weaving | 750 |

OSHA established Permissible Exposure Limits (PEL) for over 5100 hazardous substances to protect employees from exposure. Hence, local, regional, national, and international agencies should initiate awareness programs about the impact of pollutants on human health and ensure proper implementation of International standards in the textile industry. Achieving this goal would result in huge global advantages, such as decreased air pollution, improved productivity, and lower medical expenses for workers.

## Conclusion

Cotton dust exposure in the textile sector causes several health problems including byssinosis, asthma, lung cancer, and even impairs cardiovascular functions. As we are aware the textile manufacturing business generates a large amount of indoor pollutants and chemical pollutants during processing, which can cause not only environmental issues but also health issues and can lead to death if exposed for a long time. Textile workers' exposure to endotoxin and cotton dust, as well as their respiratory outcomes and other health-related issues, are explored in depth. Also, the sources of Particulate Matter, Carbon Dioxide, Carbon Monoxide, and Formaldehyde in the textile business, as well as their possible health dangers are presented. Simultaneously, the incidence of musculoskeletal discomfort, noise nuisance, and lighting issues that textile workers encounter are provided. In conclusion, the current study stresses the need to regulate and apply international standards (e.g., WHO, OSHO requirements) in the textile sector to prevent short- and long-term occupational illness.

The following recommendations are devised on earlier research and studies to enhance the textile industry's safety and health conditions. In the ginning, spinning, and weaving sections, modernizing the industries with modern machinery and technology may help to ease several challenges. Poor humidity control in the workroom causes cotton dust. As a result, excellent humidity control in the workroom may help to reduce the cotton dust concentration. Workers must be made aware of the diseases linked to cotton dust, indoor pollution, and chemicals. Personal Protective Equipment (PPE) such as face masks, earplugs, and safety gloves should be provided to workers to prevent their exposure to dust, noise, and chemicals. Dust Particle control equipment and even an IAQ overseeing system should always be established and monitored to avoid textile workers from being exposed to cotton dust particles. Appropriate lighting should be given at the workplace to reduce eye strain. There should be appropriate and proper ventilation in the workplace to keep the air fresh and healthy. Regular medical check-ups and worker camps aid in the early detection of health conditions.

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**Competing interests**

The authors declare no competing interests.

**Authors' contributions**

Shankar Subramaniam, Naveenkumar Raju, Abbas Ganesan, Nithyaprakash Rajavel, Maheswari Chenniappan, Albert Alexander Stonier, Chander Prakash, Alokesh Pramanik, Animesh Kumar Basak designed this study. Shankar Subramaniam, Naveenkumar Raju, and Abbas Ganesan collected, analyzed, and interpreted the data. Naveenkumar Raju, Abbas Ganesan, written the original draft of the paper. Shankar Subramaniam, Nithyaprakash Rajavel, Maheswari Chenniappan, Albert Alexander Stonier, Chander Prakash Alokesh Pramanik, Animesh Kumar Basak performed editing and proof reading.

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**Ethical considerations**

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc.) have been completely ob-served by the authors.

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