CURRENT OPINION

Wood dust and asthma

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Purpose of the review

Review recent developments on asthma associated with wood dust, given the increasing scale of wood handling and processing activities globally.

Recent findings

Work in wood industries is associated with a significantly increased risk of respiratory symptoms, rhinitis and asthma. This can be attributed to traditional processing techniques and newer technologies producing complex bioaerosol exposures, which may include chemicals. Meta-analysis studies indicate strong evidence for wood dusts as occupational sensitizers for asthma, but the underlying mechanisms remain poorly understood. The global prevalence of asthma in wood workers ranges between 6–18% and for rhinitis 16–33%. Exposure estimates show wide variation. Risk factors include atopy and exposure to certain wood species, elevated current and cumulative particulate exposures.

Summary

Future studies should focus on better characterization of wood dust allergens and other bioaerosol components, specific immunoglobulin E responses to different wood species, pathophysiological mechanisms underlying asthma, and modelling dose–response relationships using refined exposure metrics for dust particulate and other bioaerosol components. There is a need for improved health-based international exposure standards and effective workplace control measures to reduce exposures to wood dust particulate (hard and soft woods), endotoxin and β-glucan, to reduce the risks of asthma in wood workers.

Keywords

allergy, exposure, occupational asthma, wood dust, work-related asthma

INTRODUCTION

Wood is regarded as one of the world's most important renewable natural resources, and it is estimated that approximately 1700 million m^3 of forest is extracted for industrial purposes annually [1]. Although global figures are not readily available, it is estimated that approximately 3.6 million workers in the European Union, are exposed to wood dust, of which 700 000 work in the furniture industry [2]. Among these workers, 1.5 million are exposed to low dust levels ($<0.5\,mg/m^3$), whereas 0.2 million exposed to levels $>5\,mg/m^3$. Globally the sawmill industry, producing softwood and hardwood as raw materials, continues to expand due to the rising construction [3▪]. Various studies have identified wood dust as a risk factor for occupational asthma [4].

The aim of the review was to focus on recent studies of wood dust exposure and asthma in relation to high-risk occupations, determinants of exposure, epidemiology and risk factors for asthma in order to inform preventive approaches.

METHODS

A detailed literature search was conducted using PubMed, Google Scholar and Embase databases. Keywords for the search included "wood dust, woodworkers, wood processing industry, endotoxins, β-glucans, allergens, terpenes, asthma, occupational asthma, work-related asthma, fractional

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KEY POINTS

- Work in wood industries is associated with a significantly increased risk of respiratory symptoms, rhinitis and asthma, as well as strong evidence for wood dusts as occupational sensitizers, although these mechanisms are not well understood for most species.
- Aside from atopy, other host risk factors are less consistent.
- Environmental risk factors for asthma or rhinitis include certain wood species, current and cumulative dust particulate exposures, as evident from dose-response relationships.
- Improved health-based exposure limits, effective workplace exposure control measures, as well as education and training activities are important in mitigating the risk of rhinitis and asthma.

exhaled nitric oxide, spirometry, bronchial reversibility, exposure standards, determinants of exposure, control measures''. References listed in these articles were also screened for relevant publications. Exposure assessment studies, epidemiological studies, case reports and case series that investigated work-related asthma in wood workers in the last 2 years were reviewed. References identified in the broader search but not published within the timeframe of interest were included to provide appropriate context and continuity.

OCCUPATIONS AND POPULATIONS AT RISK

Wood dust production is the result of machines or tools used in wood cutting and processing, which generate unwanted byproducts during the work process. Airborne wood dust exposure is one of the most common occupational hazards in the wood industry [3▪]. A review of occupational exposures to wood dust in the European Union suggested that workers in construction, furniture, builders' carpentry, joinery, sawmilling and forestry were the highest exposed [5]. Furthermore, high exposures have also been reported in plywood and chipboard factories, pulp and paper mills, composting, wood pellet production, and use of wood chips in biofuel or bedding for animals [2,6]. Studies on the African continent have also reported excessive dust exposures in small to large-scale wood factories and particleboard companies [1].

CONSTITUENTS OF WOOD DUST

Wood is a hard fibrous substance, the inner core referred to as heartwood and the outer layer, sapwood. For industrial purposes, wood is classified into either hardwood or softwood. Wood (95% of weight) mainly consists of cellulose, hemicelluloses and lignin, but also large amounts of terpenes [7]. The remaining 5% constitute other high (HMW) and low molecular weight (LMW) organic and inorganic compounds, including proteins that can be extracted (''wood extractives'') [4]. Monoterpenes and resin acids (e.g., abietic and pimaric acids in pine, plicatic acid in western red cedar) released from the heartwood during sawing and planning, have been shown to have sensitizing and irritative properties. Their composition is dependent on species type, with Pine and spruce wood having higher concentrations [7]. Other chemical compounds used for wood treatment prior to processing, such as chromated copper arsenate (CCA), ACQ (alkaline copper quaternary), creosote, pentachlorophenol may also be present. In medium-density fibreboard (MDF) manufacturing, methyl diisocyanate (MDI) and phenol formaldehyde resins can also constitute important sensitizing components.

Dust generated from wood processing is therefore a heterogeneous mixture of inorganic and organic particles comprising wood fragments, microorganisms, endotoxins, mycotoxins and allergens, as well as other LMW chemical compounds that can cause adverse respiratory health effects [3▪,8–10]. Timber-colonizing gram-negative bacteria are found in high numbers in sapwood of coniferous timber. Common bacteria include *Enterobacteriaceae* family of the genera of *Rahnella*, *Pantoea*, *Enterobacter* and *Klebsiella* [6]. During industrial processing endotoxin is released into wood dust as nano-sized microvesicles. The composition of fungal spores in wood dust is heterogeneous comprising about 9% submicronic fragments, 62% large fragments and 29% spores [11]. Studies also show that *Cladosporium* spp., *Alternaria* spp., *Aspergillus* spp., *Penicillium* spp., *Trichoderma* spp., *Paecilomyces* sp., *Rhizopus* spp. and *Mucor* spp. are common in sawmills [3▪,8].

Although systematic reviews have suggested a relationship between sensitizing occupational exposures and asthma, stronger evidence has been reported for the main group of wood dust (e.g., softwood and hardwood) and certain specific wood (e.g., beech, cabreuva and oak), and moderate evidence reported for western red cedar [12]. Furthermore, only one major allergen, Trip s 1 (*Triplochiton scleroxylon*), causing asthma from obeche wood has been identified [4].

EXPOSURE ASSESSMENT

Workers in the wood processing industry are exposed to variable concentrations of hazardous agents including endotoxins, glucans and terpenes, associated with wood dust. The exposure estimates from recent studies have wide ranges viz. wood dust particulate ($0.09–25\,mg/m^3$), endotoxins ($2.5–62.2\,ng/m^3$) and fungal spores ($0.4–4 \times 10^5$ particles/m^3) (Table 1). In wood pellet production facilities (WPPF) wood dust particulate, microorganisms, endotoxin and (1→3)-β-D-glucan concentrations can reach higher values of up to $65\,mg/m^3$, $19320\,CFU/m^3$, $215\,ng/m^3$ and $1525\,ng/m^3$, respectively [2].

Okafor-Elenwo *et al.*, reported mean total viable counts (TVC) and total fungal counts of >4162 CFU/m^3 in Nigerian sawmills, while the total coliform count (TCC) was $756\,CFU/m^3$ [13]. Other studies also reported concentrations of large fungal fragments ($0.2–1\,\mu m$) ranging between $1.7–3 \times 10^5$ and submicronic fragments of $0.2–0.6 \times 10^5$ particles/m^3, but their levels were weakly correlated with spores (Table 1) [7,11]. Mean levels of resins ($7.93\,ug/m^3$), monoterpenes ($0.87\,mg/m^3$) and sesquiterpenes ($92\,ug/m^3$) were reported in saw-, sorting and planer mills [14▪]. Formaldehyde levels between 0.2 and 5 ppm were detectable in Ethiopian factories processing particleboards from eucalyptus trees [15].

The degree of wood dust generation is dependent on a number of *upstream factors* including the type of material, the machining, and the method of processing. Various studies show that MDF planing and milling creates up to six times more dust than pine wood machining; beech wood is almost 50% dustier than pine wood; and sawing of particleboard and tropical hardwood plywood is dustier than sogi wood (*Cryptomeria japonica*), softwood plywood and MDF [16▪]. Whilst certain exotic woods such as Lebombo-ironwood have also been associated with higher dust production during processing [17]. Other studies also report working with thermally modified wood influences dust levels [18–20]. Furthermore, chainsaw harvesting of hardwood (*Quercus petraea*) also produced higher dust concentrations, inversely proportional to the breast height diameter [21].

With regard to *downstream occupational factors*, exposure determinants include jobs, tasks and cleaning methods. Sawing has been identified as a high-risk exposure activity followed by sanding, milling, drilling and shaving, using handheld machines which also increase dust levels [5]. A study of joinery and furniture manufacturing industries in New Zealand, showed that work processes and tasks such as sanding, using hand tools, conventional cleaning methods (dry wiping and sweeping), using compressed air and working in small workshops (<20 workers) significantly contributed to higher dust levels [22]. A Norwegian study demonstrated that department, task and wood type were the main exposure determinants of wood dust, microbial components, resin acids and terpenes, reporting high levels for boilerman [geometric mean ratio (GMR: 1.31), kiln dryer tasks (GMR 1.25), cleaning in dry timber (GMR 1.15) and planing (GMR 1.12)] [14▪]. Awoke *et al.* [10] also demonstrated high dust exposures ($GM = 10\,mg/m^3$) in sanding and sawing departments of medium scale Ethiopian factories.

Inadequate control measures such as poor connections between extraction hoods and circular saw also result in insufficient removal of fine and light dust particulate [23]. An Iranian study of 25 furniture manufacturing workshops, demonstrated workshop size and window/door area was associated with higher dust levels [24]. Furthermore, absence of local exhaust ventilation (LEV), incorrect positioning of general air conditioners, use of compressed airlines and sweeping dust from furniture, clothes, work surfaces and processing tools were associated with higher dust levels. Recently, Cui *et al.* [25] showed that higher mill cutter speeds were associated with an increase in dust levels.

PATHOPHYSIOLOGICAL MECHANISMS

The mechanisms underlying asthma and rhinitis associated with wood dust are not fully understood. Although sensitization has been reported for certain species, the mechanisms remain unclear [28]. Although specific immunoglobulin E (IgE) sensitization has been reported in woodworkers, Type 1 allergy is not considered to be a major factor. It is estimated that only 20% of patients working in the wood industry referred for clinical evaluation demonstrate sensitization [4]. Kespohl *et al.* [29] demonstrated that exposure to wood dust can also induce irritative as well as allergic respiratory disease and that the prevalence of sensitization is much higher for tropical (30%) than nontropical wood species (3%). Vandenplas *et al.* [30] also reported that workers exposed to LMW agents such as wood dust were more likely to present with chest tightness at work, daily sputum production and late asthmatic reactions.

EPIDEMIOLOGY

A meta-analysis based of 19 population studies reported a pooled relative risk of asthma of 1.53 (95% confidence interval [CI] 1.25–1.87) [28,31]. Although the overall global prevalence of asthma in wood workers, is 6–18%, its prevalence in Africa appears to be lower (3–7%) [32]. The prevalence of rhinitis appears to be much higher ranging between 16% and 33% [32]. Certain wood species such as Pine, Mahogany, African teak, Red cedar and Imbuia

Table 1. Summary of recent exposure assessment studies conducted in wood processing workplaces (publications are listed from the most recent)

Reference	Country	Wood species	Dust fraction	*N*	Industry/job type	Wood dust conc GM (mg/m^3)	Endotoxin conc GM (EU/m^3)	Fungal particle conc GM (particle/m^3)
Awoke *et al.* 2021 [10]	Ethiopia	Not stated	Total	40	Wood workers	10.27	–	–
Jacobsen *et al.* 2021 [26■]	Denmark	Not stated	Inhalable	S1: 1610 S2: 940	Wood workers	1.00 0.60	– –	–
Baykan & Senemtaşi 2021 [27]	Turkey	Not stated	Respirable Inhalable	30 5	Furniture workers	3.72–28.18 4.36–25.07	– –	–
Straumfors *et al.*, 2020 [14■]	Norway	Spruce (*Picea abies*), Pine (*Pinus sylvestris*)	Thoracic	501	Saw and planer mills	0.09	2.5	Spores: 4×10^4 Fragments: 20×10^4
Mohammadyan *et al.* 2020 [9]	Iran	Not stated	Inhalable	100	Furniture workers	22.3*	–	–
Dimou *et al.* 2020 [21]	Greece	*Quercus pertaea, Fagus Sylvatica, Pinus brutia*	Inhalable	24	Forestry chainsaw operators	4.84	–	–
Asgedom *et al.* 2020 [15]	Ethiopia	Eucalyptus	Inhalable	152	Particle-board factory	4.66	62.2	
Straumfors *et al.*, 2018 [7]	Norway	Spruce (*Picea abies*), Pine (*Pinus sylvetris*)	Thoracic	501	Sawmill workers	0.09	3.0	Spores: 0.4×10^5 Fragments: 2×10^5 Large fragments: 1.7×10^5 Submicronic size fragments: 0.2×10^5
			Inhalable	112		0.72	17	Spores: 0.4×10^5
Afanou *et al.*, 2018 [11]	Norway	Spruce (*Picea abies*)	Thoracic	69	Sawmill workers	–	–	Spores: $1.4 \times 10^{5*}$ Large fragments: $3 \times 10^{5*}$ Submicronic size fragments: $0.6 \times 10^{5*}$

GM, geometric mean; *N*, no. of samples.
*Arithmetic mean.

have been associated with a higher asthma and rhinitis prevalence. Fibre- and chipboards and *Mansonia* sp. are also associated with a high prevalence of rhinitis. The prevalence of asthma (4–24%) and rhinitis (39–59%) appears to be higher in recent studies than a previous review (Table 2) [32].

RISK FACTORS

There are various environmental and host risk factors associated with adverse respiratory health outcomes including asthma, among workers exposed to wood dust (Table 3).

Host-related factors

Jacobsen *et al.* [26▪] reported strong associations between atopy and respiratory outcomes such as wheeze and ocular-nasal symptoms respectively in a 6-year longitudinal study of furniture workers (Table 2). A study of workers in a rubber wood sawmill factory by Chaiear *et al.* [41] found that atopy (odds ratio [OR] = 3.63; 95% CI = 1.88–7.0) was significantly associated with upper respiratory symptoms. Bolund *et al.* [42] reported an exposure–response relationship in female smokers (OR = 8.47, 95% CI = 0.9–82.4) for decline in forced expiratory volume in 1 s (FEV_1) among wood dust-exposed workers, but not in men. Similarly, Chaiear *et al.* [41] reported that females had a two-fold (OR = 2.03; 95% CI = 1.10–3.78) increased odds of upper respiratory symptoms. Furthermore, a recently completed study of Mozambiquan wood processing workers also showed that workers with work-related ocular-nasal symptoms (WRONS) were more likely to be atopic or female. Increasing age was also significantly associated with bronchial reversibility [43]. Moscato *et al.* [44] have suggested that an increased preponderance of some occupational allergic reactions in women probably reflects differences in sociocultural roles and allergen exposures due to the gendered distribution of work.

Environmental factors

A study of Ethiopian wood workers demonstrated that a history of past wood dust exposure (OR = 2.09, 95% CI 1.09–4.01) and work experience >5 years (OR = 9.0 95% CI 5.3–16.0) were significantly associated with chronic respiratory symptoms among wood workers (Table 2) [10]. This is consistent with other studies of wood workers in India [34] and Iran [36], reporting associations between employment duration and respiratory symptoms and/or lung function decline. The level of exposure to wood dust was also associated with respiratory symptoms and impaired lung function in Danish and Nigerian workers [26▪,35]. The Indian study further reported that job type and use of electrical tools were significant predictors of abnormal peak expiratory flow (PEF) [34].

Our recent studies of Mozambiquan wood processing workers, also demonstrated that certain wood species were associated with an increased risk of airway symptoms. Mutondo wood was associated with both WRONS (OR = 6.93, 95% CI 3.76–12.77) and asthma symptoms (OR = 2.32, 95% CI 1.24–4.34), while Missanda (OR = 5.74, 95% CI 3.67–8.98), Panga-panga (OR = 2.12, 95% CI 1.43–3.12) and Mahogany bean species (OR = 1.82, 95% CI 1.15–2.87) were only associated with WRONS [43].

Exposure–response relationships

A study in the Danish furniture industry demonstrated positive exposure-response relationships between current wood dust exposure and daily coughing (trend test, $P = 0.01$), with OR 1.44 (95% CI 1.08–1.91) in the highest exposure tertile. However, no clear trends were seen between current wood dust exposure and ocular-nasal symptoms [26▪]. Furthermore, a 6-year follow up study of furniture workers also showed a significant exposure-response relationship between wood dust exposure and decline in lung function [42]. Exposure–response relationships have also been demonstrated for asthma hospital readmissions, with a two-fold increased risk of readmission observed in workers with high dust exposures (>0.07 mg/m^3) in the previous year [45].

In the recent Mozambiquan study, positive dose-response relationships were demonstrated between wood dust particulate and both WRONS and asthma [46]. Although current dust particulate levels >4.68 mg/m^3 were associated with a three-fold increased risk of WRONS, increasing cumulative dust exposure was associated with increasing risks for both work-related asthma symptoms and fractional exhaled nitric oxide (FeNO) levels.

PREVENTION

Policy, regulatory frameworks, and exposure standards

Wood dust control policies, legislation and compliance with exposure standards are important strategies for risk reduction to prevent the adverse respiratory health effects. The GESTIS substance database [47] publishes occupational exposure limits (OELs), and OELs range from 0.5 to 10 mg/m^3 (Table 4) and vary between countries and professional organizations that have proposed these

Table 2. Epidemiological studies of wood workers with airway symptoms, rhinitis and asthma and identified risk factors

Reference (Author, country)	Industry/Job type	N	Exposure	Prevalence	Risk factors	Predictors of symptoms OR (95% CI)
Abdel *et al.*, 2021, Egypt [33]	Joinery workshops	100	Wood dust	Rhinitis: 59% Wheeze: 34% Shortness of breath: 70% Asthma: 24%	NR	NR
Bose *et al.*, 2021, India [34]	Wood workers	105	Wood dust	Cough: 61% Chest tightness: 15% Breathlessness: 19% Abnormal PEF: 68%	Duration of work, Electrical tools use, Job category	*Abnormal PEF:* - electrical tools: 1.4 (0.5–4.5)* - design makers:1.5 (0.1–1.9)* - job years: 1.6 (1.3–2.1)*
Awoke *et al.*, 2021, Ethiopia [10]	Wood workers	496	Wood dust	Cough: 61% Phlegm: 52% Wheeze: 45% Breathlessness: 43%	Past wood dust exposure, Work years>5, Training on H&S	*Respiratory symptoms:* - past wood dust exposure: 2.1 (1.1–4.0) - work years>5: 9.0 (5.3–16.0) - no H&S training: 3.4 (1.2–9.5)
Nafisa *et al.*, 2020 Nigeria [35]	Wood workers	370	Black Akpara, Congo Akpara, White Akpara, Mansonia, Mahogany, Iroko	Runny nose: 13% Wheeze: 6% Breathlessness: 15.6% Tight chest: 20.5%, Impaired LFT: 37% (% predicted ratio < 0.75)	Degree of exposure to wood dust	*Respiratory symptoms:* - degree of wood dust exposure: $P < 0.001^{\#}$ *Impaired LFT:* - degree of wood dust exposure: $P < 0.001^{\#}$
Jacobsen *et al.*, 2021, Denmark [26■]	Furniture workers	S1: 2032 S2: 1886	Wood (hard-, softwood), Wood veneers, Mixed wood	*Workers in both studies* (*Study 1 / Study 2*) Conjunctivitis: 7% / 7% Nasal symptoms: 47% / 39% Wheeze:17% / 17% Asthma ever: 6% / 7% Current asthma: 4% / 5%	Smoking, atopy, wood dust	*Nasal symptoms:* - atopy: 17 (12.3–24.1) - smoking: 1.5 (1.2–1.8) - wood dust: 1.2 (1.0–1.5) *Wheeze ever:* - atopy: 2.9 (2.3-3.7)
Grny *et al.*, 2020 Poland [2]	Pellet production facilities	28	Wood dust, Microbial pollutants	Nose/eye irritation: 38% Runny nose:13% Wheezing: 25% Productive cough: 13%	Wood dust concentration	*Nose/eye irritation:* - wood dust>3mg/m^3: 3 (0.2–59.9)
Hosseini *et al.*, 2020 Iran [36]	Wood workers	534	Hardwood	Rhinorrhea: 4% Wheezing: 25% Phlegm: 41% Chest tightness: 38% Cough: 40%	Duration of work	*Phlegm:* - employment>15 yrs: $P < 0.001^{\#}$ *Chest tightness:* - employment >15 yrs: $P = 0.014^{\#}$ *Cough:* - employment>15 yrs: $P = 0.013^{\#}$ *FEV$_1$/FVC:* - Wood vs. office workers: $P = 0.031$~
Sütçü *et al.*, 2019 Turkey [37]	Sawmill factories	413	Red pine (*Pinus brutia*)	Wood dust-related allergic symptoms: 23% Burning/red eyes: 27%	Duration of work	*Wood dust allergic symptoms:* - employment duration: $P = 0.014^{\#}$ Eye irritation due to wood dust: - employment duration: $P = 0.026^{\#}$
Asgedom *et al.*, 2019, Ethiopia [38]	Particleboard factories	147	Eucalyptus	Wheezing: 45% Shortness of breath: 24% Phlegm: 27% Productive cough: 31%	Exposed vs. controls	*FEV$_1$/FVC:* - exposed vs. unexposed: $P = 0.004$~ *Respiratory symptoms:* - exposed vs. unexposed: $P < 0.001^{\#}$
Fentie D, *et al.*, 2019, Ethiopia [39]	Wood workers	140	Wood dust	Asthma: 11%	Exposed vs. controls	*Asthma:* - exposed vs. unexposed: $P = 0.021^{\#}$
Paraskevaidou *et al.*, 2019, Greece [40]	Furniture workers	83	Wood dust: particleboard and fibreboard	Wood dust exposed: Rhinitis: 17% Asthma: 9% Chemical exposed: Rhinitis: 26% Asthma: 23%	Office workers vs. wood dust and chemical exposed	*Asthma/Rhinitis:* - exposed vs. unexposed: $P = 0.004^{\#}$ *Methacholine challenge test:* - exposed vs. unexposed: $P = 0.031^{*}$ *PEF analysis by OASYS:* - exposed vs. unexposed: $P = 0.001^{*}$

PEF: peak expiratory flow, PPE: personal protective equipment, H&S: health and safety, LF: lung function test, NR: Not reported.
Chi-square test; ~ Independent-sample t-test, *Mean ranks by Kruskal-Wallis test.

Table 3. Risk factors for wood-dust related asthma

Environmental factors
• Wood species
• Exposure duration
• Current exposure concentration
• Cumulative exposure
Host-related factors
• Genetic
• Atopy
• Upper airway symptoms and rhinitis
• Smoking
• Gender (gendered distribution of work)

Source: Chamba and Nunes, 2016 [32].

standards. While professional organizations such as the American Conference of Governmental Industrial Hygienists (ACGIH) have increasingly proposed health-based limits, those promulgated by countries generally base these limits on access to technology and socio-economic considerations [48]. This probably explains the discrepancies between the OEL's for similar types of wood across different countries and ultimately results in sub-optimal respiratory health protection of workers in most countries.

Workplace control measures to reduce exposures

Engineering controls

Proper use of dust extraction systems is regarded as the most important technical workplace control

Table 4. Recommended occupational exposure limits reported for wood dust in various countries

Country (organization)	Type of exposure limit	Type of wood dust*	TWA	OEL (mg/m^3)
US (ACGIH)[h]	TLV TLV	Western red cedar All species	8h 8h	0.5[g] 1
US (NIOSH)[i]	REL	Hard wood dust, Soft wood dust, Western red cedar dust	8h	1
US (OSHA)[j]	PEL PEL	Wood dust (Western red cedar) Wood dust (all dusts except Western red cedar) Wood dust (all dusts except Western red cedar)	8h 8h 15min	2.5 5 10
Australia	OEL	Hardwoods Softwoods	8h 15min	1 5
United Kingdom (HSE)	WEL	Dust, hardwood	8h	3[e,f]
Sweden (SWEA)	OEL	Dust, hardwood Dust, wood, total dust Softwood dust	8h 8h 8h	2 2 2
Norway	OEL	All species	8h	2
Denmark	OEL OEL	Dust, wood, total dust Dust, wood, total dust Softwood dust Softwood dust	8h 15min 8h 15min	2 4 1 2
Germany (AGS)	MAK MAK	Dust, hardwood Dust, hardwood	8h 8h	5[b] 2[d]
The Netherlands	OEL	Dust, hardwood Health-based OEL is $0.2 mg/m^3$	8h	2
European Commission	BOELV	Dust, hardwood	8h 8h	2[a,b] 3[a,b,c]
New Zealand	OEL	Hardwoods Softwoods	8h 8h	1 2
South Africa	OEL	All species	8h	5

Adapted from Rijs, K, *et al.* [5]. *Type of wood - based on entry in GESTIS Substance Database where applicable).
[a]Inhalable fraction: If hardwood dusts are mixed with other wood dusts, the limit value shall apply to all wood dusts contained in the mixture.
[b]Bold type = BOELV.
[c]Limit value until 17.01.2023.
[d]Reference value that represents the state of the art. Individual measures are related to this value.
[e]Inhalable fraction.
[f]If hardwood dusts are mixed with other wood dusts, the WEL shall apply to all the wood dusts present in that mixture.
[g]Inhalable particulate matter.
[h]ACGIH (2015).
[i]NIOSH Pocket Guide to Chemical Hazards - Wood dust.
[j]https://www.cdc.gov/niosh/pel88/wooddust.html.

measure for reducing wood dust exposures [16▪]. Pǎlubicki *et al.* [16▪] demonstrated that the use of main and auxiliary sawdust extraction connectors together ensured the highest reduction in wood dust exposures to 0.5 mg/m^3 during sawing activities. Baranski *et al.* [49] and Cui *et al.* [25] showed that correct design of the upper suction hood for dust extraction from circular saws, and the correct positioning of dust collecting hoods can improve the efficiency of dust removal. Furthermore, optimizing cutting parameters and the location of operators in relation to these machines can contribute to reducing the spatial distribution of MDF dust levels. Other studies by Douwes *et al.* [22] also demonstrated that local exhaust ventilation and the use of vacuum cleaners in joinery and furniture manufacturing were able to reduce dust concentrations.

Information and training

Awoke *et al.* [10] also demonstrated that wood workers with no occupational health and safety training were more likely (OR = 3.38, 95% CI 1.20–9.49) to have chronic respiratory symptoms. A recent study by Top *et al.* suggested that factors such as employees' perception of health risks associated with wood dust, knowledge of tasks generating wood dust, dust exposure limits and safe work practices impacted on the use of ventilation systems [23].

Although Awosan *et al.* [50] found a high level of awareness (81%) of workplace hazards among Nigerian sawmill workers, less than two-thirds had adequate knowledge of hazards in their workplace, which the authors attributed to low educational level and training on occupational health and safety. Another study by Asgedom *et al.* [51] revealed a higher proportion of workers with improved knowledge and attitude among permanent compared to temporary workers. Furthermore, effective use of PPE was dependent on adequate personal protective equipment (PPE) access which was not evident in the latter group.

These studies highlight the need for proper education of workers and managers on the relevant hazards associated with work in the wood industry, improved occupational hygiene practices and consistent use of appropriate personal protective devices, through education and training programmes to minimize the risks associated with wood dust.

CONCLUSION

This review has highlighted that occupational exposure to wood dust in various wood industries, remains a concern for both high- and low-and middle-income countries due to its association with respiratory symptoms, asthma and decline in lung function. This risk may be enhanced due to traditional processing techniques as well as the development of new wood products that produce complex exposures of bioaerosols, which may also include chemicals. Whilst there have been recent advances in characterizing these exposures, significant gaps still remain in preventive strategies, including health protective exposure standards to reduce risk.

Future studies should focus on better characterization of wood allergens and other bioaerosol components, characterization of specific IgE responses to different wood species, improved understanding of the pathophysiological mechanisms underlying asthma, modelling of the dose–response relationships using refined exposure metrics that go beyond wood dust particulate levels, and harmonization of various international exposure standards for wood dust particulate (hard and soft woods), endotoxins and β-glucans, to reduce the risks of asthma in wood workers.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
▪ of special interest
▪▪ of outstanding interest

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