Archives of Environmental & Occupational Health

ISSN: 1933-8244 (Print) 2154-4700 (Online) Journal homepage: https://www.tandfonline.com/loi/vaeh20

Personal inhalable dust and endotoxin exposure among workers in an integrated textile factory

Yifokire Tefera, Vivi Schlünssen, Abera Kumie, Wakgari Deressa, Bente E. Moen & Magne Bråtveit

To cite this article: Yifokire Tefera, Vivi Schlünssen, Abera Kumie, Wakgari Deressa, Bente E. Moen & Magne Bråtveit (2020): Personal inhalable dust and endotoxin exposure among workers in an integrated textile factory, Archives of Environmental & Occupational Health, DOI: 10.1080/19338244.2020.1743958

To link to this article: https://doi.org/10.1080/19338244.2020.1743958

© 2020 The Author(s). Published with license by Taylor & Francis Group, LLC

Published online: 20 Apr 2020.

Submit your article to this journal

Article views: 223

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=vaeh20

ARCHIVES OF ENVIRONMENTAL & OCCUPATIONAL HEALTH
https://doi.org/10.1080/19338244.2020.1743958

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

Personal inhalable dust and endotoxin exposure among workers in an integrated textile factory

Yifokire Tefera[a,b,c], Vivi Schlünssen[d,e], Abera Kumie[a], Wakgari Deressa[a], Bente E. Moen[b,c], and Magne Bråtveit[b]

[a]Department of Preventive Medicine, School of Public Health, College of Health Sciences, Addis Ababa University, Addis Ababa, Ethiopia; [b]Department of Global Public Health and Primary Care, University of Bergen, Bergen, Norway; [c]Centre for International Health, Department of Global Public Health and Primary Care, Faculty of Medicine, University of Bergen, Bergen, Norway; [d]Department of Public Health, Environment, Occupation and Health, Danish Ramazzini Centre, Aarhus University, Aarhus, Denmark; [e]The National Research Centre for the Working Environment, Copenhagen, Denmark

ABSTRACT

The aim of this study was to determine personal exposure to inhalable dust and endotoxin levels among workers in an integrated cotton-processing textile factory and exposure variability across the different work sections. Full shift measurements were carried out using inhalable conical samplers with 37 mm glass-fiber filters. Personal inhalable dust was determined gravimetrically, and endotoxin levels were analyzed by kinetic chromogenic Limulus Amebocytes Lysate assay. The geometric means of personal dust and endotoxin concentrations were 0.75 mg·m^{-3} and 831 EU·m^{-3}, respectively. The highest dust and endotoxin concentrations were observed in carding section (1.34 mg·m^{-3} and 6,381 EU·m^{-3}, respectively). Altogether, 11% of dust and 89% of endotoxin samples exceeded workplace exposure limits. This study showed a moderate correlation between inhalable dust and endotoxin ($r = 0.450$, $p < 0.001$). Our findings indicate that low dust exposure does not guarantee a low exposure to endotoxin.

ARTICLE HISTORY
Received 7 February 2019
Accepted 2 March 2020

KEYWORDS
Endotoxin; Ethiopia; inhalable cotton dust; integrated textile factory; personal exposure

Introduction

The textile sector is one of the key parts of the development agenda in the Ethiopian Growth and Transformation Plan (GTP II), and it contributes USD 2.18 billion worth of production to the national economy and provides about 174,000 jobs.[1] A survey from 2013 performed by the International Textile Manufacturers Federation (ITMF) showed that 26% of the cotton used in textiles globally was moderately or seriously contaminated with foreign matter. In a 2009 survey, the ITMF reported that the cotton used in Ethiopian textiles was moderately (33%) and seriously (67%) contaminated by organic matter such as leaves, feathers, debris, etc.[2] Thus, a large number of textile workers are exposed to cotton dust and its contaminants, including endotoxin from bacterial contamination,[3,4] and both the dust particles and endotoxin might cause a variety of different respiratory health problems.[5–8]

The concentrations of cotton dust and endotoxin in the working environment are greatly affected by various conditions such as the quality of the cotton, the production rate, the ventilation system, the processing method, and the method of dust sampling and analysis.[9–11] Most studies have reported higher levels of dust and endotoxin in the first cotton processing sections, including ginning, opening, carding, and recycling, than in the last stages comprising the finishing and garment sections.[4,12–14] Previous studies in different countries have shown mean personal inhalable cotton dust exposures ranging from 0.81 to 2.39 mg·m^{-3}.[4,10,15–17] In an Ethiopian textile mill, the mean stationary respirable dust concentration was found to be 1.75 mg·m^{-3}, but those measurements did not cover all work sections of the integrated textile factory and endotoxin was not measured.[18]

A few studies have also analyzed the levels of personal inhalable endotoxin exposure in textile mills, and the results have varied from 191 EU·m^{-3} to 2,566 EU·m^{-3}.[4,10,17,19] In some of these textile mills, only the first part of the textile production was included. The old textile mills are different than the new, modern integrated textile mills that are established today

CONTACT Yifokire Tefera yifoomitu@yahoo.com Department of Preventive Medicine, School of Public Health, College of Health Sciences, Addis Ababa University, Addis Ababa, Ethiopia.

© 2020 The Author(s). Published with license by Taylor & Francis Group, LLC
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way.

that also include garment departments with sewing sections. A typical integrated textile factory has four main production process departments (spinning, weaving, finishing, and garment) that are integrated into a single clothing production line. Endotoxin exposure has not been adequately assessed in the typical work sections of integrated textile factories in any developing countries, and exposure assessments and workplace inspection efforts have been focused only on cotton dust measurements and might not provide sufficient information to evaluate the risk of respiratory effects among workers in the integrated textile factories and to recommend adequate control measures.

The overall aim of this study was to investigate personal inhalable dust and endotoxin exposure levels in the different work sections of an integrated textile factory in Ethiopia in order to provide current information for a respiratory health protection program among workers in the growing textile sector in low-income countries. We also wanted to study the correlation between dust exposure and endotoxin exposure. Few laboratories analyze endotoxin, and it would be useful to know if the dust levels could also indicate the level of endotoxin in the inhalable dust fraction. This would simplify the risk assessment of such workplaces.

Methods and materials

This exposure study was conducted in an integrated textile factory comprising the complete production line from raw cotton to the final products of yarn, fabrics, and garments. Of the total 130 registered textile and garment factories in Ethiopia, 20 of them are integrated textile factories. Three textile factories across the country fulfilled the criteria of being cotton-processing integrated textile factories, i.e. having four departments (spinning, weaving, finishing, and garment), and processing only cotton. From these three textile factories, one textile factory was chosen at random for this exposure assessment.

Study setting

The textile factory is situated 550 km northwest from the capital Addis Ababa. It was established in 1961 and is one of the oldest textile factories in Ethiopia. The factory has four departments – spinning, weaving, finishing, and garment – in separate but interconnected sections in one building, except for the garment department that is located in a separate building. In 2011, the factory replaced all of the old machines in the spinning department and some of the machines in the weaving department. The spinning and weaving sections have a central, mechanical air conditioning system and a movable local exhaust ventilation system around the machines. In addition the carding and ring frame sections have local exhaust ventilation through openings in the floor.

A total of 1,136 production workers were present at the time of data collection, including the maintenance and engineering departments. The four departments were further categorized into sections. In the spinning department there were three sections: carding (79 workers), open end (67), and ring frame (86). In the weaving department there were the two sections: preparatory (68) and fabric making (126). In the finishing department there was the batching section (68), and in the garment department there was the sewing section (136). The total number of workers in the seven sections was 630, excluding engineering and maintenance workers. Workers were selected for personal sampling from all seven sections. Descriptions of the tasks of each section are briefly presented in Table 1.[20]

Sampling strategy

Previous area measurements in the same factory showed the highest concentration and variability of dust in the spinning department and in the fabric-making section of the weaving department.[18] Thus, four of the work sections (carding, open end, ring frame, and fabric making) were considered to be high-exposure groups with greater variability, whereas the other three work sections

Table 1. Summary of task descriptions and final products of the different sections in the integrated textile factory.

Department	Section	Description of tasks or activities	Products
Spinning	Carding	Removing impurities and smoothing the raw cotton Tasks include blowing, carding, and drawing	"Silver" rope-like fiber
	Open end	Separating the silver rope into single fibers	Yarn with high hairiness
	Ring frame	Twisting the drafted strand with the required count and strength. Tasks also include roving and auto coning	Higher-quality yarn with uniform structure and strength
Weaving	Preparatory	Tasks include warping, winding, twisting, doubling, and sizing	Strong, smooth, and elastic warp yarn
	Fabric making	Combining warp and weft components to make a woven structure using a loom	Fabric
Finishing	Batching	Inspecting the quality of the fabrics, bleaching, and dying	Good appearance of the fabrics
Garment	Sewing	Pulling of sheets, cutting, and sewing	Clothing

Table 2. Description of the sampling strategy by working departments and work sections in an integrated textile factory.

Production departments	Work sections	Total number of workers	Number of workers selected for air sampling	Number of personal air samples collected
Spinning	Carding	79	12	18
	Open end	67	10	15
	Ring frame	86	10	15
Weaving	Preparatory	68	8	12
	Fabric making	126	10	15
Finishing	Batching	68	8	11
Garment	Sewing	136	6	10

(preparatory, batching, and sewing) were considered to be low-exposure groups. According to the recommendation for exposure assessment by Rappaport,[21] repeated personal air samples were collected from 6 to 12 workers for each similar exposure group. A total of 96 personal air samples were collected from 64 workers as indicated in Table 2. Thus, repeated personals air samples were taken from 32 of these 64 workers. About 10% of the total working population in the four production departments was involved in the exposure measurements.

Exposure measurement and analysis

Personal inhalable cotton dust was collected for an average duration of 4.3 hours (3.8–5.8 hours) in the period of January and February, 2017. Dust sampling was carried out using a conductive plastic inhalable conical sampler (CIS; JS Holdings, Stevenage, UK) mounted with a 37 mm glass-fiber (GFA) filter (Whatman International Ltd, Maidstone, UK).[22] The sampling head was attached to the worker's upper chest or lapel, not more than 30 cm away from the nose-mouth region. The pump operated at a flow rate of 3.5 l·min^{-1}. One blank per field site was collected every day as a quality control.[23] A checklist was completed regarding tasks performed during sampling, characteristics of the working environment (e.g. air temperature, humidity, and type of ventilation system), and personal protection used. The mean temperature in the working sections was 23.1–35.5 °C, and the mean humidity was 40.6–47.1%. The sampled filters were transported as hand luggage to Denmark, for analysis.

The dust samples were analyzed gravimetrically (pre - and post - sampling weighing). An equilibration period of a minimum of 24 hours (22 °C, 45% relative humidity) preceded filter weighing, which was performed using a Mettler UMT2 analytical scale (Mettler-Toledo Ltd, Greifensee, Switzerland) with 0.001 mg precision. The result was expressed in mg·m^{-3}. Sample extraction and endotoxin analysis were performed as described by Spann et al.[24] in one of the duplicate dust samples that was randomly chosen. Briefly, the filters were extracted in 5 mL of pyrogen-free water with 0.05% (v/v) Tween-20. The samples were initially shaken for 60 minutes on a Multi Reax digital shaker (Heidolph Instruments GmbH, Schwabach, Germany) and then centrifuged for 15 minutes at 1000 *g*. Subsequently, 1 mL of the supernatant was removed, aliquoted in four 0.1 mL portions, and stored at −20 °C. The extracts were analyzed for endotoxin in pyrogen-free water (1:200 dilution) using a quantitative kinetic chromogenic Limulus Amebocytes Lysate test (Kinetic-QCL 50-650 U kit, Lonza, Walkersville, Maryland, USA). Results were given in EU·m^{-3}.

Statistical analysis

The arithmetic means (AM) of inhalable dust and endotoxin concentrations were stratified by department and work section. All further statistical analysis was performed on log-transformed data because the distributions of the exposure data were skewed. Accordingly, the geometric mean (GM) and geometric standard deviation (GSD) were calculated to determine the average exposure and the variability of measurements, respectively. Analysis of variance (ANOVA) and Student's t-test were performed to compare exposure levels between departments and work sections. The correlation between inhalable dust and endotoxin concentrations was analyzed by Pearson's correlation test. The statistical analysis was performed by using the Statistical Package for Social Sciences (SPSS) Version 22 software.

Results

A total of 96 samples were collected from the seven sections of the four departments in the integrated textile factory. One sample was discarded during laboratory analysis due to an overload of dust on the filter. Sixty-four workers participated in exposure sampling, and 89% were operators and 11% were transporters or

Table 3. Personal exposure to inhalable dust, endotoxin, ratio of endotoxin per mg dust and correlation between dust and endotoxin across departments and sections in an integrated textile factory.

Department and section	n	Inhalable dust ($mg{\cdot}m^{-3}$) AM (Range)	Inhalable dust GM (GSD)	Endotoxin ($EU{\cdot}m^{-3}$) AM (Range)	Endotoxin GM (GSD)	Ratio of endotoxin to dust ($EU{\cdot}mg^{-1}$ dust) AM (Range)	Ratio GM (GSD)	Correlation b/n dust and endotoxin r
Spinning	48	1.3 (0.1 – 8.8)	0.71 (2.8)*a	4041 (80 – 30801)	1560 (5.0)**a	3876 (106 – 15432)	2271 (3)**a	0.585**b
-Carding	18	2.1 (0.5 – 8.8)	1.34 (2.4)	8665 (2344 – 30801)	6381 (2)	6526 (611 – 15432)	5032 (2)	
-Open end	15	0.8 (0.2 – 3.6)	0.57 (2.1)	1824 (495 – 7077)	1315 (2)	2784 (407 – 4811)	2323 (2)	
-Ring frame	15	0.9 (0.1 – 7.6)	0.42 (3.1)	1017 (80 – 5877)	375 (4)	1966 (106 – 8083)	902 (4)	
Weaving	27	1.1 (0.1 – 6.7)	0.78 (2.3)*a	1944 (74 – 11492)	1086 (3.0)	2242 (350 – 17938)	1394 (2)*a	0.650**b
-Preparatory	12	0.7 (0.1 – 2.1)	0.47 (2.4)	2593 (74 – 11492)	992 (4)	3756 (350 – 17938)	2097 (3)	
-Fabric making	15	1.5 (0.7 – 6.7)	1.16 (1.8)	1424 (455 – 4818)	1167 (2)	1031 (584 – 1332)	1005 (1)	
Finishing[c]	11	2.2 (0.3 – 10.5)	1.25 (2.8)	465 (34 – 1667)	258 (3)	340 (32 – 1406)	206 (3)	0.571
Garment[d]	9	0.5 (0.4 – 0.7)	0.46 (1.2)	393 (12 – 2476)	76 (6)	358 (25 – 2464)	112 (4)	−0.052
All	95	1.3 (0.1 – 10.5)	0.75 (2.6)**e	2647 (12 – 30801)	831 (5.4)**e**f	2656 (3418)	119 (5)**e**f	0.450**b

AM = Arithmetic mean; GM = Geometric mean; SD = Standard deviation; GSD = Geometric standard deviation; n = Number of samples.
[a]Test for differences in means between sections within departments.
[b]Test for correlation between inhalable dust and endotoxin.
[c]Batching section in the finishing department.
[d]Sewing section in the garment department.
[e]Test for differences in means between sections in the factory.
[f]Test for differences in means between departments in the factory.
*p-value < 0.05.
**p-value < 0.001.

cleaners. None of the workers used respiratory protective devices at work.

The overall personal inhalable dust exposure had a GM of $0.75\,mg{\cdot}m^{-3}$ (Table 3). The highest level of inhalable dust exposure was measured in the carding section (GM = $1.34\,mg{\cdot}m^{-3}$), while the lowest measurements were recorded in the ring frame, sewing, and preparatory sections ($0.42\,mg{\cdot}m^{-3}$, $0.46\,mg{\cdot}m^{-3}$, and $0.47\,mg{\cdot}m^{-3}$, respectively). The inhalable dust exposure was significantly different between the sections within both in the spinning department (at $F = 7.1$, $p < 0.05$) and the weaving department (at $F = 1.7$, $p < 0.05$). About 11% of the cotton dust measurements were above the workplace exposure limit (WEL) of the Health and Safety Executives (HSE) of the UK of $2.5\,mg{\cdot}m^{-3}$.[25]

The overall personal endotoxin exposure had a GM of 831 $EU{\cdot}m^{-3}$ (Table 3). The highest personal endotoxin exposure was measured in the carding section (6,381 $EU{\cdot}m^{-3}$), while the lowest exposure was found in the sewing section in the garment department (76 $EU{\cdot}m^{-3}$). The mean endotoxin exposure level was significantly different among the sections in the spinning department (at $F = 35.6$, $p < 0.001$). About 89% of the endotoxin measurements were above the occupational exposure limit value of 90 $EU{\cdot}m^{-3}$ recommended by the Dutch Expert Committee on Occupational Standards.[26]

The ratio of endotoxin per mass of dust was higher in the first two departments of spinning and weaving (2,271and 1,394 $EU{\cdot}mg^{-1}$, respectively) than in the last two departments of finishing and garment (206 and 112 $EU{\cdot}mg^{-1}$, respectively) along the production line of the factory. A significant difference was observed within the departments and work sections at $F = 27.8$, $p < 0.001$ and $F = 22.3$, $p < 0.001$, respectively.

Generally, the mean exposure levels of both the inhalable dust and endotoxin showed significant differences across work sections, but only the endotoxin exposure showed such a difference across departments ($p < 0.001$).

There was a moderate linear relationship between personal inhalable dust and endotoxin exposure ($r = 0.45$, $p < 0.001$) (Table 3). The correlation was strong and significant in the weaving and spinning departments ($r = 0.65$, $p < 0.001$ and $r = 0.58$, $p < 0.001$, respectively), but no such relationship was seen in the finishing and garment departments ($r = 0.571$ and $R = -0.052$ at $p > 0.05$, respectively).

Discussion

We used standardized and well proven methods for dust and endotoxin sampling and analysis. All analyses were performed in laboratory facilities at Denmark, and gravimetric analysis was in accordance with HSE guidelines.[23] The duration between sampling and analysis was on average two months, and the samples were stored at a temperature of 8 °C. It has earlier been shown that even storage of samples for more than one year at 7 °C did not affect the endotoxin level.[27]

The results of the dust sample analysis were compared to the HSE WEL for personal inhalable dust of $2.5\,mg{\cdot}m^{-3}$ while handling raw and waste cotton, although the limit does not apply to dust from weaving, dyed cotton, or finished articles.[25] Because we used personal inhalable dust sampling, it was deemed reasonable to compare our samples with the HSE WEL. In Ethiopia and in many other developing countries there are no laboratories offering endotoxin analyses today, and it is a challenge even to be able to analyze dust samples. Although Ethiopia has an occupational exposure limit value of 1 $mg·m^{-3}$ for raw cotton, there is no clearly stated limit for exposure to the dust fraction.[28] Also Ethiopia has no occupational exposure limit values of its own for endotoxin. Therefore limit values from other countries were used for comparison.[25,26]

Personal inhalable dust exposure in this study was similar to the levels found in studies conducted in Nepal textile factories (0.81 $mg·m^{-3}$)[4] and in UK cotton mills (1.09 $mg·m^{-3}$).[15] However, our study shows higher levels than a study performed in a Greek cotton textile mill (0.16 $mg·m^{-3}$),[29] and among cotton textile workers in Germany where 71% of the samples were below 0.21 $mg·m^{-3}$.[30] The work place hygiene improvements prior to the study in Germany and the efforts toward better work environments in Greece might have reduced the dust concentrations in those studies. The results of the present study were, however, lower than what was seen in Shanghai textile mills (1.87 $mg·m^{-3}$),[10] in Lancashire textile weavers (1.55 $mg·m^{-3}$),[16] and in Turkish cotton mills (2.39 $mg·m^{-3}$).[17] These higher exposure levels could be due to old machines, poor ventilation systems, or measurements only being taken from the high-exposure sections in the cotton processing line.

Similar to the dust levels, the findings of this study revealed higher endotoxin exposure levels than studies from German textile factories (450 $EU·m^{-3}$).[30] The endotoxin levels were also higher than what were found in Turkish cotton mills (191 $EU·m^{-3}$),[17] even though the inhalable cotton dust exposure was higher in Turkish cotton mills. This could possibly be due to better quality cotton in Germany and Turkey as well as to more hygienic housekeeping practices.[2] However, the results of our study are lower than in the studies from Nepal (2,160 $EU·m^{-3}$),[4] and Shanghai (1,334 $EU·m^{-3}$).[10] The higher endotoxin exposures in those studies could be due to high dust concentrations in the sampling locations in Shanghai and the fact that samples were also taken from the recycling section in the Nepalese study. Studies have also showed, concentration of endotoxin at the workplaces could be varied by the variations in the endotoxin analysis technique[24] and the quality of the cotton used.[9]

The exposure concentrations and the ratio of endotoxin to dust were higher in the first step in the production process compared to the last step, i.e. between the carding and the sewing sections. A Turkish study measured higher dust exposure in the carding section (3.49 $mg·m^{-3}$) compared to the packing section in the garment (1.16 $mg·m^{-3}$), thus showing a similar decline in exposure further along the production process.[17] A similar pattern of decreasing endotoxin concentration from the spinning department to the garment department was found in Nepal.[4] One reason for this could be that in the first stage of the process, the raw cotton from the farms might contain bacterial contaminants from contact with soil, leaves, debris, and animal excretions that are gradually removed by industrial processing and cleaning activities at the different stages of the production process.[2,4] The considerably lower ratio of endotoxin to dust along the production process from spinning to garment in our present study supports this suggestion. This is also reflected in the moderate correlation between inhalable dust and endotoxin in the total dataset, while the correlation was relatively strong in the spinning and weaving departments. Thus it appears that increasing levels of inhalable dust exposure might predict higher endotoxin exposure in the initial cotton processing sections, but this association is not present in all parts of the production process, and these results must be used with caution. Likewise, a moderate relationship between dust and endotoxin was found in the Nepalese textile industry.[4]

A statistically significant difference was seen in the inhalable dust exposure levels across work sections ($p < 0.001$), and further statistical analysis showed variation in the average concentration of inhalable dust between the work sections in the spinning and weaving departments. The relatively high dust concentration in the batching section of the finishing department could be due to manual handling when picking and lowering fabric beams on the ground that might emit non-cotton dust. .

The variation in endotoxin concentration was also significant both between working sections and between departments in the factory ($p < 0.001$). Moreover, the endotoxin concentration variation was significant between working sections in the spinning department. The low endotoxin concentration in the ring frame section might be linked to the low level of inhalable dust, less hairiness in the yarn being made in this process,[20] and/or the presence of functional local exhaust ventilation system in the section. The higher endotoxin concentration in the preparatory and fabric making sections in the weaving department could be due to higher inhalable dust concentration, fabrics being dumped on dusty surfaces, poor housekeeping practices, and/or the presence of old machines in the work environment.

This study was conducted with limited resources, thus personal inhalable dust measurements were not repeated in different seasons. This would be of interest for future studies in addition to studies at different production volumes. However, strength of the study was the use of established methods for dust and endotoxin sampling. Also, the days of sampling were chosen by the researchers and were not influenced by the workers or employers, thus increasing the likelihood of having representative samples.

This is the first study of personal inhalable dust and endotoxin exposure in an integrated cotton-processing textile factory in sub-Saharan Africa. The information is considered to be valid also for factories with similar production in Ethiopia, as well as in other low-income settings. The information obtained should be taken into account and be a basis for exposure reduction programs in the integrated textile factories of similar types both in Ethiopia and in other low-income countries.

Conclusions and recommendation

Generally the personal inhalable dust exposure level measured in this study was 11% higher than the WEL of the UK. Furthermore, the level of personal endotoxin exposure was 89% higher than the Dutch Experts' recommendation. Thus our study indicates that the lower level of inhalable dust exposure does not guarantee safe exposure to endotoxin. Both personal dust and endotoxin exposure levels were higher at the beginning of the textile processing and were lower in the last work section of the process. Exposure monitoring programs, including education, awareness, and provision of personal respiratory protective devices based on exposure priority; improving ventilation systems; and regular housekeeping should be strengthened to protect the respiratory health of workers in the integrated textile factories.

Acknowledgments

We would like to thank the company management and the Regional Bureau for Labor and Social Affairs for permission and facilitation to conduct the study and the factory workers for participating in the study.

Conflicts of interest

The authors declare that they have no competing interest.

Ethical considerations

Ethical approval was obtained from the Institutional Review Board with a Protocol number: 057/16/SPH. Access to the factory was granted by the factory management, written informed consent was obtained from all the study participants, and participation in the study was voluntary.

Funding

This research was funded by the Norwegian Program for Capacity Building in Higher Education and Research for Development, Norwegian Agency for Development Cooperation (Norad).

References

1. National Planning Commission. *Federal Democratic Republic of Ethiopia: Growth and Transformation Plan II (GTP II) (2015/16-2019/20)*. Vol. I. Addis Ababa, Ethiopia: National Planning Commission; 2016.
2. ITMF. *Cotton Contamination Surveys; 2003●2005●2007●2009●2011●2013*. Zurich, Swizerland: International Textile Manufacturers Federation; 2014.
3. Lai PS, Hang JQ, Valeri L, et al. Endotoxin and gender modify lung function recovery after occupational organic dust exposure: a 30-year study. *Occup Environ Med*. 2015;72(8):546–552. doi:10.1136/oemed-2014-102579.
4. Paudyal P, Semple S, Niven R, Tavernier G, Ayres JG. Exposure to dust and endotoxin in textile processing workers. *Ann Occup Hyg*. 2011;55(4):403–409. doi:10.1093/annhyg/meq084.
5. Lai PS, Christiani DC. Long term respiratory health effects in textile workers. *Curr Opin Pulm Med*. 2013;19(2):152–157. doi:10.1097/MCP.0b013e32835cee9a.
6. Khan AW, Moshammer HM, Kundi M. Industrial hygiene, occupational safety and respiratory symptoms in the Pakistani cotton industry. *BMJ Open*. 2015;5(4):e007266. doi:10.1136/bmjopen-2014-007266.
7. Daba WS, Chercos DH, Dessie A, et al. Cotton dust exposure and self-reported respiratory symptoms among textile factory workers in Northwest Ethiopia: a comparative cross-sectional study. *J Occup Med Toxicol*. 2018;13(1):13. doi:10.1186/s12995-018-0194-9.
8. Ali NA, Nafees AA, Fatmi Z, Azam SI. Dose-response of cotton dust exposure with lung function among textile workers: MultiTex study in Karachi, Pakistan. *Int J Occup Environ Med*. 2018;9(3):120–128. doi:10.15171/ijoem.2018.1191.
9. WHO. Recommended health-based occupational exposure limits for selected vegetable dusts. Report of a WHO study group. *Tech Rep Ser*. 1983;684:1–78.

10. Mehta AJ, Wang XR, Eisen EA, et al. Work area measurements as predictors of personal exposure to endotoxin and cotton dust in the cotton textile industry. *Ann Occup Hyg*. 2008;52(1):45–54. doi:10.1093/annhyg/mem061.
11. Campopiano A, Basili F, Angelosanto F, et al. Field comparison of two inhalable samplers used in Italy to measure the wood dust exposure. *Int J Occup Environ Health*. 2016;22(2):159–166. doi:10.1080/10773525.2016.1200206.
12. Dube KJ, Ingale LT, Ingle ST. Respiratory impairment in cotton-ginning workers exposed to cotton dust. *Int J Occup Saf Ergonom: JOSE*. 2013;19(4):551–560. doi:10.1080/10803548.2013.11077009.
13. Lane SR, Nicholls PJ, Sewell R. The measurement and health impact of endotoxin contamination in organic dusts from multiple sources: focus on the cotton industry. *Inhal Toxicol*. 2004;16(4):217–229. doi:10.1080/08958370490277164.
14. Mayan O, Da Costa JT, Neves P, Capela F, Pinto AS. Respiratory effects among cotton workers in relation to dust and endotoxin exposure. *Ann Occup Hyg*. 2002;46(suppl_1):277–280. doi:10.1093/annhyg/46.suppl_1.277.
15. Simpson JC, Niven RM, Pickering CA, Oldham LA, Fletcher AM, Francis HC. Comparative personal exposures to organic dusts and endotoxin. *Ann Occup Hyg*. 1999;43(2):107–115. doi:10.1016/S0003-4878(98)00083-0.
16. Raza SN, Fletcher AM, Pickering CA, Niven RM, Faragher E. Ventilatory function and personal breathing zone dust concentrations in Lancashire textile weavers. *Occup Environ Med*. 1999;56(8):520–526. doi:10.1136/oem.56.8.520.
17. Bakirci N, Kalaca S, Francis H, et al. Natural history and risk factors of early respiratory responses to exposure to cotton dust in newly exposed workers. *J Occup Environ Med/Am Coll Occup Environ Med*. 2007;49(8):853–861. doi:10.1097/JOM.0b013e3180dca598.
18. Woldeyohannes M, Bergevin Y, Mgeni AY, Theriault G. Respiratory problems among cotton textile mill workers in Ethiopia. *Br J Ind Med*. 1991;48(2):110–115. doi:10.1136/oem.48.2.110.
19. Keman S, Jetten M, Douwes J, Borm P. Longitudinal changes in inflammatory markers in nasal lavage of cotton workers. *Int Arch Occup Environ Health*. 1998;71(2):131–137. doi:10.1007/s004200050260.
20. Lawrence CA. *Advances in Yarn Spinning Technology*. England: Woodhead Publishing; 2010.
21. Rappaport SM, Kupper LL. *Quantitative Exposure Assessment*. El Cerrito, CA: Stephen Rappaport; 2008.
22. Kenny LC, Aitken R, Chalmers C, et al. A collaborative European study of personal inhalable aerosol sampler performance. *Ann Occup Hyg*. 1997;41(2):135–153. doi:10.1016/S0003-4878(96)00034-8.
23. HSE. *General Methods for Sampling and Gravimetric Analysis of Respirable, Thoracic and Inhalable Aerosols*. London: Health and Safety Executives; 2014.
24. Spaan S, Doekes G, Heederik D, Thorne PS, Wouters IM. Effect of extraction and assay media on analysis of airborne endotoxin. *Appl Environ Microbiol*. 2008;74(12):3804–3811. doi:10.1128/AEM.02537-07.
25. HSE. *EH/40 Workplace Exposure Limits Containing the List of Workplace Exposure Limits for Use with the Control of Substances Hazardous to Health Regulations (as Amended)*. 3rd ed. UK: HSE; 2018.
26. DECOS. *Endotoxins. Health-Based Recommended Occupational Exposure Limit*. The Hague: Health Council of the Netherlands, 2010. Publication no. 2010/04OSH.
27. Douwes J, Versloot P, Hollander A, Heederik D, Doekes G. Influence of various dust sampling and extraction methods on the measurement of airborne endotoxin. *Appl Environ Microbiol*. 1995;61(5):1763–1769. doi:10.1128/AEM.61.5.1763-1769.1995.
28. Ministry of Labor and Social Affairs. *Occupational Safety and Health Directives*, 2008. Addis Ababa, Ethiopia: Federal Democratic Republic of Ethiopia; 2008.
29. Boubopoulos NJ, Constandinidis TC, Froudarakis ME, Bouros D. Reduction in cotton dust concentration does not totally eliminate respiratory health hazards: The Greek study. *Toxicol Ind Health*. 2010;26(10):701–707. doi:10.1177/0748233710377773.
30. Oldenburg M, Latza U, Baur X. Exposure-response relationship between endotoxin exposure and lung function impairment in cotton textile workers. *Int Arch Occup Environ Health*. 2007;80(5):388–395. doi:10.1007/s00420-006-0145-0.