Original Article

Personal cotton dust exposure in spinning and weaving sections of a textile factory, north Ethiopia

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Abstract

Background: The growing textile industry in Ethiopia has had a profound impact on employment opportunities in the country. Exposure to cotton dust is well recognized to cause respiratory illnesses among workers. However, exposure assessments of textile workers are rarely conducted in Ethiopia. This study aimed at measuring personal exposure to total cotton dust among textile factory workers and to explore the variability of dust exposure in different factory work sections.

Materials and methods: Workers from 11 work sections of a textile factory participated in a personal sampling of dust. One hundred full-shift personal air samples were taken in the breathing zone of workers using 37mm close-faced plastic cassettes fitted with mixed cellulose acetate (MCA) filters connected to Casella pumps at an air flow rate of 2 liters/min. The concentration of total cotton dust was analyzed gravimetrically.

Results: Personal total dust exposure (geometric mean; geometric standard deviation) were higher in the cleaning department (1.84; 2.37mg/m^3) than in the weaving (0.61; 1.65) and spinning departments (0.60; 2.31). The personal exposure of workers in the blowing and cleaning section of the spinning department, of workers in sizing section of the weaving department, and of workers involved in cleaning work surfaces, exceeded the occupational exposure level of 1mg/m^3.

Conclusions and recommendations: The cotton dust concentration among 5 in 6, 4 in 6, and 10 in 12 workers working in blowing and cleaning, sizing, and work surface cleaning, respectively, was above the recommended occupational exposure level of 1mg/m^3. Dust exposure reduction is highly advised. [*Ethiop. J. Health Dev.* 2020; 34(2):97-105]

Key words: Total cotton dust, personal exposure, textile factory, similar exposure group

Introduction

Ethiopia has been engaged in intensive socio-economic development since 2003/2004, transforming its economy from agrarian-orientated to industrialized in the attempt to reach lower-middle-income country status by 2025 (1). The average annual economic growth rate of 11% for 2004-2016 (2,3) has been achieved through the implementation of a series of long-term plans, such as the Growth and Transformation Plan (GTP) (4). Prioritized industries primarily include textiles and garments, leather and leather products, sugar, cement, metal and engineering, chemicals, pharmaceuticals and agro-processing. While the poverty-reducing benefits of industrial growth are obvious, uncertainties regarding the impact of industrial processes on human health and the environment are a growing concern. There are considerable health risks related to occupational exposures in these industries, and little is being done to reduce them (5). At the time of data collection (December 2016), there were 12 operational textile factories in the country, located mainly in Dire Dawa city administration, and in Tigray, Amhara, Oromia, and Southern Nations, Nationalities and Peoples' regions. These factories mainly process raw cotton into yarn and fabrics.

Workplace health hazards in textile industries include inhalation of cotton dust (6), and may also include inhalation of ground-up plant matter, bacteria, fungi, soil particles, and pesticide residues. Dust components can accumulate in cotton fibers during the growth of cotton plants, harvesting, and subsequent handling and processing, as well as in storage (7). Thus, dust exposure in textile factories comprises not only exposure to cotton dust but also to various other constituents. Exposure assessment in the cotton industry is limited in Ethiopia. A pioneering study in a textile mill in the 1990s using a vertical elutriator indicated variation of dust concentration by type of workplace, with concentrations exceeding the permissible exposure level for respirable dust in the blowing, carding, and drawing sections (6) (range: 0.86-3.52 mg/m^3). Subsequently, two local studies (8,9) examined dust levels in textile factories, but they had methodological limitations as they comprised only area measurements, which are not considered representative for personal exposure in the breathing zones of workers. In addition, they did not address work areas such as waste pack houses, where there might be significant exposure to cotton dust.

Measuring personal total and inhalable dust is a common exposure assessment method to evaluate cotton dust concentration in workplaces (10-12). The technology used to sample total dust is relatively cheap and feasible for epidemiological investigations in developing countries to assess the relative importance of occupational exposure to cotton dust.

The present study aimed to measure the level of personal exposure to cotton total dust and explore the variability between the work processes in one of the largest textile factories located in north Ethiopia. The outcome of the study will serve as a baseline for practitioners in occupational health to evaluate exposures to cotton dust

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in the growing textile industry. It will also identify processing units with high exposures, where factory managers should establish control and preventive strategies that address the hazards of cotton dust exposure.

Materials and methods

Study area and setting: We undertook the study in one of the largest cotton processing factories in northern Ethiopia. The factory has been operational since 1986 as a public enterprise. The total number of workers at the time of the study was about 1,500, working in three shifts of eight hours each. The morning shift starts at 07:00. There were about 141 workers in the morning shift at the time of the data collection (May 2017). This integrated factory involved three main processing sections: spinning, weaving and garment. It produces mainly yarns, fabrics, and bed sheets for export (>70%) and some for local markets. The study was undertaken in the spinning and weaving sections for reasons of increased cotton dust concentration relative to the garment section, which was observed during the feasibility study earlier. The cotton process flow of the study subject is sketched out in Figure 1.

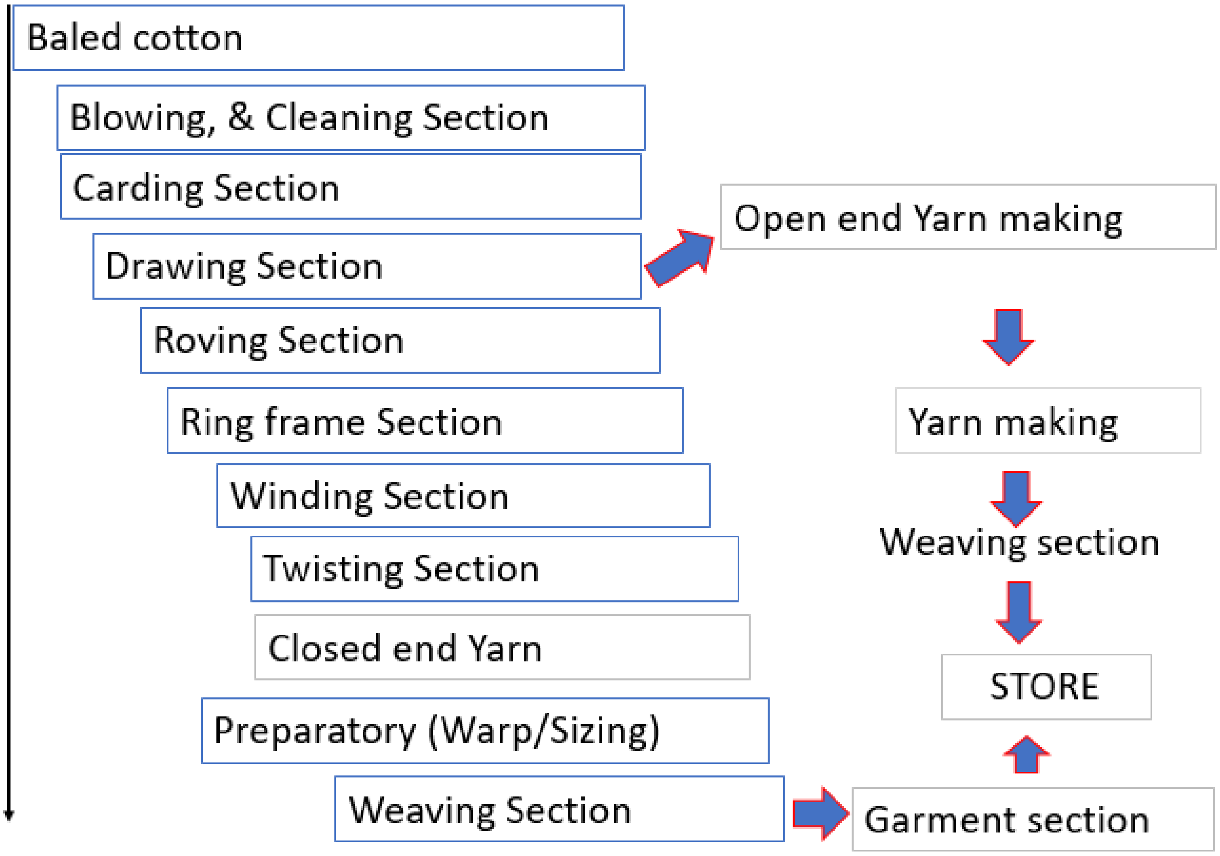

Figure 1: **The textile mill flow process (the process involves two technologies: closed ended, the very traditional one involving different processes in different machines; the open ended that integrated the tasks of roving, ring frame winding, and twisting in one row of machines. The output in both cases is yarn production)**

Study design and period: A cross-sectional design with quantitative measurement of dust concentration, complemented by workplace observations, was carried out from April to May 2017.

Selection of study subjects and sample size: There were three main work processes involving spinning, weaving, and cleaning that involved 11 work sections. The cotton dust was hypothesized to vary by cotton processing work sections, and we assumed cotton dust exposure within the individual work sections would be similar for all workers in each section, as workers share the same task and working environment. First, we identified the number of workers in each work section who had been working at least 6 months or more. All workers in each work section were considered where the number of workers was ≤5. At least 50% of the source subjects were considered for sampling in similar exposure groups (SEGs) with >5 workers. We selected 100 workers for personal sampling (Table 1).

The sample size approximated the recommendations for quantitative exposure assessments made by the US National Institute for Occupational Safety and Health, and Rappaport *et al.* (13-14), considering 5-10 measurements from each SEG.

Table 1: **Source population and sample size grouped by departments and similar work sections**

Work section (SEG)	Number of workers (source population)	No. of sampled subjects
Spinning department	**75**	**50**
Blowing and cleaning	6	6
Carding and drawing	5	4
Open end	4	4
Roving	3	2
Ring frame	31	20
Winding	20	10
Twisting	6	4
Weaving department	**54**	**38**
Warping	9	6
Sizing	9	6
New weaving	20	16
Old weaving	16	10
Cleaning	**12**	**12**
Total	**141**	**100**

Data collection methods

a. Cotton dust sampling devices

A light (566g) vacuum air sampler pump (AirChek52, Sidekick Pump SKC Ltd) was mounted to each worker's waist and connected with a plastic tube to a 37mm closed-faced Millipore plastic cassette sampling head fitted with dust-arresting filters. Filters were conditioned for 24 hours before and after sampling. When a pump is fully charged it can operate for 12-16 hours. The pump flow was calibrated with a ball type rotameter at 2 liters/min by taking the reading at the center of the floating ball (Figure 2a). It has an adjustable flow rate accessory that is capable of maintaining ±5% of the set flow rate. This personal sample pump connected to a sampling head is widely used in air pollution and exposure assessment studies (Figure 2b) (10-12,15). The exposure to cotton dust was determined by placing the sampling head in the breathing zone of the worker (Figure 2c). The average durationof sampling was 6.7 (SD±0.9) hours, corresponding to 84% of the shift duration. Lunch time was not included for sampling, given the absence of exposure during this period. The sampling took 20 days (April-May 2017). After sampling, the sampling heads (cartridges) with dust filters were stored in two card boxes holding 50 cartridges each, in a room environment, both in the field and in the laboratory. Exposed cartridges and field blanks were kept together to share the same environment.

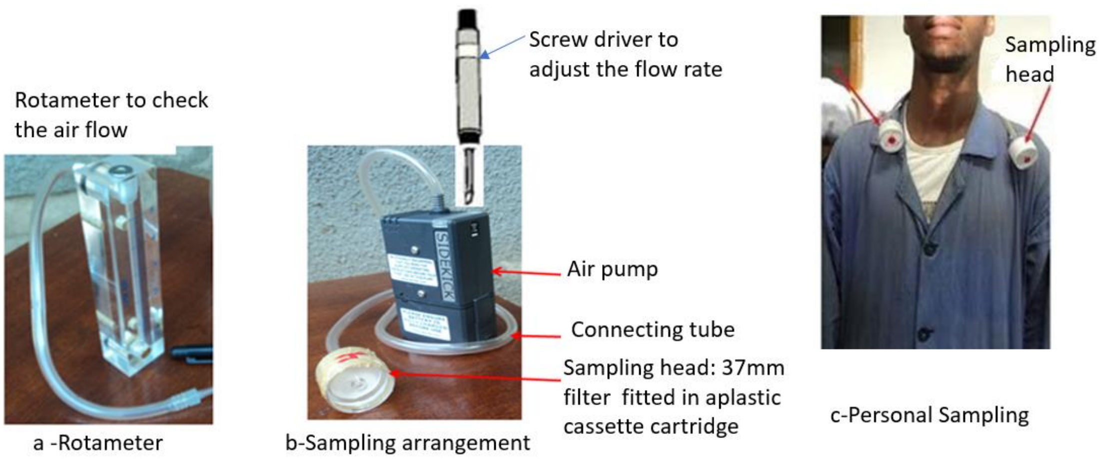

Figure 2: **Cotton dust sampling arrangement**

A scientific micro balance (Mettler Toledo, Fisher Scientific Ltd), with a sensitivity of 0.001mg, was used for both pre-weighing and post-weighing of the sampling filters at the SINTEF Molab research laboratory , Norway. The MCA filters were desiccated for 24 hours before weighing to avoid moisture that might have been absorbed during sampling and storage. The room temperature and relative humidity (RH) were measured by a digital thermo-hygrometer and ranged from 20-22ºC and 47-50%, respectively.

Filters were pre-weighed in milligrams using two decimal digits and recorded in a log-book that was designed for this purpose. Filters were then assembled in the pre-coded Millipore cassettes. The date of weighing, post-weight results after sampling and the micro-environment (ºC and RH%) were also recorded in the log-book.

b. Recording workplace characteristics and behavior of workers

We used an observational checklist to record the characteristics of the workplaces in terms of the type of work operations, type of machines and materials involved in dust generation, apparent intensity of cotton dust, ventilation conditions, type of personal protective equipments (PPEs) used, and the raw materials and their sources. This was done during walk-through inspections.

A separate data sheet was developed to record the data of each sampling subject in terms of codes of the sample, IDs, hand pump code, job category, the pre- and post-sampling flow rates, and start and end time of sampling. A second data sheet with the ID of the subject and job category was used to document the activities/tasks of the subject during the sampling process.

c. Data collection team

Two data collectors, one lab expert and one field supervisor, handled the data collection. The data collectors had a background in environmental health (BSc and MPH) and were trained for one day on the purpose, methods and ethical issues. They had previous similar experience in dust sampling. The tasks of the data collectors were mainly to assemble the sampling instruments on the bodies of the study subjects, check the flow rate frequently, observe the behavior of the study subjects that might affect the dust sampling, and record all the data in the appropriate data sheets.

Data management and analysis: Demographic data and information on cotton dust sampling were first recorded in a data sheet, which was transferred to an Excel sheet on the same day of sampling. The Excel data sheet was exported to SPSS for data exploration and analysis.

The cotton dust in reference to each filter was weighed to calculate the concentration using the following equation (gravimetrically):

$$\text{Concentration mg/m}^3 = \frac{\left(\text{Weight of filter after sampling, mg} - \text{Weight of filter before sampling, mg}\right) - \text{Weight blank}}{\text{Pump flow rate (lpm) X sampling time in minutes X 1000 l/m}^3}$$

The weight of the sampled cotton dust was determined from the difference between the weight of the exposed and the unexposed filter, as determined by a micro-balance. This was followed by subtracting the field blank. The field blank was taken to the study site to share the same environment with the actual sampling devices used for exposure. We calculated the total air volume during sampling duration using a pump flow rate of 2 liters/min. The concentration of cotton was then calculated by dividing the net weight of cotton dust by the total volume of air.

The linear concentration data was heavily skewed to the left (Kolmogorov-Smirnov normality test, $p<0.001$). The cotton concentration was subjected to a natural log transformation to assume normal distribution ($p=0.1$). Descriptive statistics were used to describe the exposure level. One-way analysis of variance (ANOVA) was used to compare the level of cotton concentration between work sections.

In Ethiopia, the occupational exposure limit (OEL) for raw dust is 1mg/ m^3 (16). Although this OEL does not indicate the type of dust, the level is in line with OELs in other countries. For instance, in Sweden, the OEL for cotton total dust is 1mg/m^3 (17).

Data quality assurance: We used a weighing micro balance that has 0.001mg detection limit, calibrated with a standard analytical weight. The sample weights were managed by SINTEF Molab, Norway, an accredited dust-free research laboratory. The sampling head was inspected every hour during sampling in order to check for the presence of any barrier to the inlet of air flow. Sample transport and storage were managed using a standard operating procedure to ensure the quality of data. Sampling was done for full shift hours in workplaces (Figure 3). Field blanks were used to control exposure errors.

Figure 3: **Supervising personal cotton dust sampling in the workplace**

Ethical considerations
Ethical clearance was obtained from the Institutional Review Board of the College of Health Sciences at Addis Ababa University. Permission for data collection was sought from the selected textile factory after submitting the participants' information sheets.

Verbal informed consent was obtained from individual respondents after providing appropriate information that briefly described the purpose, data collection process and the subjects' individual rights. The right to leave the study any time was respected without any effect on the individuals' rights. Anonymity was used to keep data confidential. Access to the data sheets and database was allowed only to the research team members.

Results
Description of study subjects: We studied 100 subjects composed of 43 males and 57 females. The average duration in employment was 22 years (SD $\pm$10.5). In terms of educational background, 46% of subjects were illiterate, and 36% and 18% had completed primary and secondary education, respectively. In terms of the work sections, 50%, 38% and 12% worked in spinning, weaving and cleaning jobs, respectively.

The factory process observations: The baled cotton raw material was hosted from various cotton-growing farms in Ethiopia, such as sites in Awash, Metema and Humera. The quality of cotton is judged by the length of the fibers. Information from the quality control lab showed that the strength and length of the cotton fibers varied depending on the growing site.

The cotton dust generation very much depended on the process units according to the statement of the quality expert. The blowing-cleaning section, followed by carding and drawing section, tended to have flying fluffs that were visible on the floor and around the working zone of the workers. Flying fluffs are pieces of cotton that escape the processing of yarn making. The ring frames produced a lot of flying fluff cotton dust, which was observed around the working surface of the machines. The winding and twisting sections had less visible cotton dust and flying fluff compared to the ring frame section. The sources of dust were multiple and are summarized as follows:

- The operations of cotton mills, using blowing, carding, drawing fibers, spinning, winding, and twisting machines, are sources of cotton dust. The generation rate of cotton dust, however, differs by these work sections according to the process line.
- Another frequent source of dust was when broken threads were sorted by an operator in spinning, and afterwards where yarns are processed.
- The local exhaust ventilation system, which is designed to remove dust from the surface of machines and floor, was another source of dust. The exhaustion of dust and fluff triggers nearby fluff and cotton dust to suspend in the air.
- Jet streams used by cleaners and workers to remove fluff and cotton dust from surfaces (floor, wall, machine, human body surfaces) highly disperse dust in workplaces.
- Human activities involved in manual loading and unloading of the cotton generated cotton dust and flying cotton, commonly during bale arranging and cleaning in the waste pack and filter house. The manual handling and cleaning of cotton waste by waste packers also created dust.

Ventilation system: The spinning and weaving sections have mechanical air supply and extraction systems. Conditioned fresh air is supplied to work surfaces through a network of ducts arranged close to the roof. Roving and ring frame machines were installed with a local dust removal exhaust system that moves linearly along the operating machines.

The moisture content and the air temperature of the supplied air are controlled centrally to improve the strength of the fibers. The relative humidity and respective room temperature ranged from 32-50% and 27-30^{o}C in spinning, and 63-78% and 20-25^{o}C in weaving.

Personal protective equipment and health services: Workers were supplied with personal protective devices such as gowns, working clothes, gloves, shoes, head covers and goggles. Cloth dust masks, locally made, were capable of trapping coarse cotton dust only. The utilization of such masks was not uniform across workers. The factory fully provides free medical assistance using a factory-based clinic, referrals to hospitals and managing medical compensation.

The level of cotton dust concentration: The factory level of total cotton dust concentration was 0.69 (2.29) mg/m^3. There was variation between the three main processing units (df (2, 97)), F=11.7, $p<0.0001$), the cleaning work having the highest exposure level relative to spinning and weaving departments. Cotton concentration did not differ by educational and work duration. There was, however, a difference by sex (Table 2).

Table 2: **Total cotton dust concentration by selected demographic variables**

Variable	n	GM (GSD)	ANOVA, p-value
Sex			
Male	43	1.04 (2.29)	p<0.001
Female	57	0.51 (1.99)	
Education			
Illiterate	46	0.71 (2.43)	0.541
Primary education	36	0.61 (2.39)	
Secondary education	18	0.79 (1.74)	
Employment duration (years)			
<15	23	0.62 (2.32)	0.704
15-29	51	0.73 (2.46)	
30-35	26	0.66 (1.96)	

There was variability in the averages of the exposure to cotton dust between work sections (df (10, 89), F=10.5, p<0.001). Blowing, cleaning, sizing and warping sections had increased dust concentrations relative to other work sections. The specific jobs are related to waste packer, bale arranger, filter attendant, blowing operator, warping operator, and cleaner (Table 3).

Table 3: **Total cotton dust exposure levels in different work areas of the textile factory**

Department/Section	n	AM (SD)	Min	Max	GM (GSD)	n (%) of samples exceeding OEL of 1mg/m^3 *
	mg/m^3					
Spinning department, total	**50**	**0.84 (0.90)**	**0.035**	**5.23**	**0.60 (2.31)**	
Blowing and cleaning	6	2.76 (1.71)	0.71	5.21	2.23 (2.16)	5 (83.3)
Carding and drawing	4	0.81 (0.38)	0.46	1.32	0.74 (1.59)	1 (25)
Open end	4	0.31 (0.27)	0.04	0.68	0.20 (3.50)	-
Roving & Ring frame*	22	0.64 (0.25)	0.20	1.05	0.58 (1.61)	1 (4.5)
Winding	10	0.45 (0.29)	0.10	0.95	0.36 (2.13)	-
Twisting	4	0.44 (0.16)	0.26	0.62	0.42 (1.47)	-
Weaving department total	**38**	**0.69 (0.37)**	**0.23**	**1.67**	**0.61 (1.65)**	
Warping	6	0.94 (0.27)	0.71	1.45	0.91 (1.30)	2 (33.3)
Sizing	6	1.11 (0.37)	0.64	1.54	1.05 (1.45)	4 (66.7)
New weaving	16	0.72 (0.32)	0.36	1.67	0.67 (1.49)	2 (12.5)
Old weaving	10	0.40 (0.11)	0.23	0.53	0.39 (1.35)	-
Cleaning**	**12**	**2.53 (2.11)**	**0.32**	**7.01**	**1.84 (2.38)**	10 (83.3)
Total	**100**	**0.99 (1.15)**	**0.32**	**7.01**	**0.69 (2.29)**	**25 (25)**

* 'Total dust' is defined as all the particles (aerosols) trapped by a filter in the sampling apparatus (17).

Discussion

In this study, 25 (25%) workers had total dust concentrations above the recommended OEL that might trigger a concern of health risk. The overall total dust concentration had a geometric mean (GM) of 0.69 over the full shift work, but varied by work process. There was a variability of cotton dust concentration between work sections, and the highest levels were found in the cleaning section. There was also a difference in exposure levels by sex.

The difference in cotton dust concentration in spinning and weaving work sections is explained by the cotton processing, which is consistent with other studies (8,9). It is usually semi-processed cotton that produces increased dust in the first process lines, including cotton fibers and other particulate matters. The raw cotton in a form of ginned cotton usually has debris, such as plant and soil dusts, besides the biological cotton dust including lint or fluff (18). The cleaning process of blowing air streams, combing cotton in carding machines, and stretching and aligning efforts by drawing mills, all produce an increased concentration of cotton dust, the highest being in the blowing and cleaning machines, as also shown in previous studies (9,19). This is important in terms of valuing the likelihood of workers' exposure to high levels of cotton dust in the workplace.

The average cotton total dust concentration exceeded by about two fold the OEL of 1mg/m^3 set by the Ethiopian and Swedish Occupational Safety and Health Services (16,17) in blowing and cleaning work sections, as well as in work surface cleaning tasks. About 83% of the samples exceeded this OEL in these two working sections. The process of blowing, carding and drawing sections in the spinning department involved the stretching and aligning of the fibers of raw cotton into bundles of fibers called slivers that would be further converted into yarn. Loosely attached fibers, because of their short length, form dust when the cotton bale is opened forcefully and during manual mixing. In addition, stray fibers that are found on the work surfaces (machines, wall and floor) are easily triggered when they are moved by air streams of the ventilation system. They are easily suspended in air, as well, during floor cleaning activities. These sections are known to inherently generate high levels of cotton dust and stray fibers around the working environment. In a previous study conducted in Addis Ababa in 2010, cotton dust measurements over 8 hours in six sampling points in a textile factory indicated varying mean concentrations ranging from $2mg/m^3$ to $32.2mg/m^3$, the highest concentration being observed in the blowing, carding and drawing sections (8). Similarly, a study carried out in 2013 in an Addis Ababa textile factory, using a direct-reading dust monitor with a diameter cut-point of 4μm, showed varying mean concentrations, with the highest levels found in the blowing, carding and drawing sections (9). The high level of cotton dust in spinning sections has also been documented in other studies (20).

The present study showed a high cotton dust concentration in the weaving department, specifically in warping and sizing work sections. This has not been documented in other local studies (20). These work sections are preparatory, feeding yarn to the weaving section. We also observed an increased level of exposure among workers in the new weaving section compared to the old weaving section. This was due to the differences in the productivity of machines. We observed the mills involving new machines functioned at full capacity, while this was less than 10% in the old weaving section. The breaking of yarns was also more frequent in the new weaving mills due to the fast machine process of making fabrics.

Cleaners in spinning and weaving sections are exposed to cotton dust as a result of manual sweeping that disperses cotton dust into the indoor air. In addition, dust came from machine surfaces while they were being operated. Cleaners in the waste houses had the worst exposure level, as this task involved manual collection of waste cotton from waste storage to a bale making machine. Our observations in this work area during a walk-through inspection showed that the waste house surface area was fully covered in cotton dust. The presence of cotton dust on workers' clothes and open skin was also observed at the time of data collection. There was no local ventilation system in this work area.

It is worth noting the relatively low level of cotton dust in the open end, ring frame, winding and twisting sections; all of these are part of the spinning department. The work in these sections involves already processed yarns being fed from drawing machines, and twisting six slivers into a single yarn. Processed yarns in this way are strong, and less likely to generate cotton dust relative to the processing of raw cotton. The low level of cotton dust in these sections is consistent with similar findings in a previous study conducted in Ethiopia (19).

The appropriate use of dust masks is believed to protect the inhalation of fine particulate matter (PM) that has an aerodynamic diameter of less than 2.5μm. This type of PM is most hazardous to the lungs because of its penetration power. Using a cloth mask is unable to trap particle sizes of <5μm. Hence, work sections with elevated cotton dust concentrations relative to the OEL are likely to present workers with health effects in the long run. The US National Institute for Occupational Safety and Health recommends a particulate respirator with 95% filtering efficiency, such as N95 or equivalent P2 dust masks (7,21).

The contribution of sex to the difference in exposure must be evaluated carefully, as the same workers sharing the same environment will have equal exposure measurements, regardless of sex or other demographic factors. Demographic features do not play a critical role in deciding the level of exposure. It is usually the working characteristics that affect the level of exposure. The contribution of sex must be understood relative to the work placement. In total, 40% of female study subjects were stationed in spinning work areas that had less dust, in contrast to males who were involved in the new weaving section that had increased dust because of the full operation of cotton mills that are prone to yarn breakage, hence dust emissions into the environment. Education and work duration were not important factors affecting exposure in our study.

Generally, unprocessed cotton has inherent characteristics that release dust. Loosely attached short fibers in the raw cotton can easily detach in the process of feeding machines, cleaning, and yarn making. In addition, the frequent breaking of yarns and the number of working machine loads are associated with high levels of cotton dust in workplaces.

We used standard protocol to quantify the cotton dust concentration gravimetrically in a known accredited research laboratory in Norway. The personal cotton dust exposure measurement covering all possible work units that were associated with observation of sources of exposure was a strength of this study. Combining cotton dust measurements and observations using a checklist was useful to complement exposure data. We are aware that the use of total dust sampling heads to some extent may underestimate the inhalable dust fraction using different sampling heads (22,23). However, the use of total dust is a feasible and inexpensive method that can be considered as the first line of exposure assessment.

Conclusions and recommendations

One quarter of samples of total dust concentration in the blowing and cleaning section and tasks related to work surface cleaning exceeded the OEL. There was a significant variation in dust concentrations along the direction of the cotton process line. The factory is highly advised to reduce dust levels in the work areas to avoid the development of respiratory health problems among the workers. Accessing to high quality row cotton, provisions of exhaust ventilation, use of standard PPE can be readily applied.

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Competing interests
The authors declare that we have no financial competing interests or any conflicts in relation to this publication.

Authors' contributions
AK carried out protocol development, data collection, data management and analyses, and wrote the manuscript. MB, WD, BE, and SW were involved in protocol development, facilitating the training in dust exposure assessment, providing field work monitoring, and editing the manuscript.

Abbreviations

AM	Arithmetic mean
GM	Geometric mean
GSD	Geometric SD
GTP	Growth and Transformation Plan
MCA	Mixed Cellulose Acetate
OEL	Occupational Exposure Limit
PM	Particulate matter
PPD	Personal Protective Device
SD	Standard deviation
SEG	Similar Exposure Group

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