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Personal Dust Exposure and Its Determinants among Workers in Primary Coffee Processing in Ethiopia

Samson Wakuma Abaya[1,2,3*], Magne Bråtveit[2], Wakgari Deressa[1], Abera Kumie[1] and Bente E. Moen[2,3]

[1]Department of Preventive Medicine, School of Public Health, College of Health Sciences, Addis Ababa University, PO Box 9086, Addis Ababa, Ethiopia; [2]Occupational and Environmental Medicine, Department of Global Public Health and Primary Care, University of Bergen, Bergen, Norway; [3]Centre for International Health, Department of Global Public Health and Primary Care, Faculty of Medicine, University of Bergen, Årstadveien 21, 5009 Bergen, Norway

*Author to whom correspondence should be addressed. E-mail: samson_wakuma@yahoo.com

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Abstract

Background: Coffee processing has been shown to cause high dust exposure among the workers, but there are few studies from primary processing of coffee, and none of them is from Ethiopia. The aim of this study was to assess dust exposure and its determinants among workers in primary coffee processing factories of Ethiopia.

Methods: A total of 360 personal 'total' dust samples were collected from the breathing zone of workers in 12 primary coffee processing factories in Ethiopia. Dust sampling was performed with 25-mm three piece conductive cassettes with cellulose acetate filters attached to pumps with flow rate of 2 l min^{-1} for an average sampling duration of 410 min. The dust samples were analysed gravimetrically using a standard microbalance scale. An observational checklist was used to collect information about possible determinants of dust exposure in the work environment. Linear mixed effect regression models were used to identify significant determinants of total dust exposure.

Results: Personal total dust exposure levels varied between the three main job groups with a geometric mean (GM) of 12.54 mg m^{-3} for the machine room workers, 12.30 mg m^{-3} for the transport workers, and 1.08 mg m^{-3} for hand pickers. In these three groups, 84.6%, 84.1% and 2.6% of the samples exceeded the occupational exposure limit for organic total dust of 5 mg m^{-3}, respectively. The mixed-effects model for the machine room workers explained 21% of the total variance in total dust exposure, and showed that vigorously pouring coffee from a dropping height was associated with an about two times increase in exposure. For the transport workers, the mixed-effects model that included pouring method of coffee beans, number of huller machine in the room, mixing coffee, and feeding hopper explained 32% of total variance in personal total dust exposure.

Conclusion: About 84% of the dust samples among machine room and transport workers in primary coffee processing factories were above the occupational exposure limit value for organic dust. Proper control measures are necessary to reduce the exposure.

Keywords: coffee dust; coffee Ethiopia; exposure determinants; personal exposure; primary coffee factory

Introduction

Ethiopia is a major producer of coffee in Africa by producing about 500 000 tonnes every year (Amamo, 2014). Ethiopia is believed to be the birth place of *Coffea arabica*, which obtained its name from Kaffa where coffee was first discovered in the south-western highlands of Ethiopia (Wiersum *et al.*, 2008). Coffee contributes to about 10% of the Ethiopian growth domestic product and accounts for more than 25% of the foreign currency income (Chauhan *et al.*, 2015; Gebreyesus, 2015). In Ethiopia, about 15 million people depend on coffee production directly or indirectly for their living (Gray *et al.*, 2013).

Ethiopia produces exclusively Arabica Coffee, which is grown in three regional states: Oromia, Southern Nation's Nationalities and People's Region (SNNPR), and Gambella. About 99% of the coffee production comes from the Oromia and SNNPR regions (Musebe *et al.*, 2007). More than 90% of the coffee is produced by small-scale farmers that on the average owns about 0.5 hectare of land (Mekuria *et al.*, 2004).

Primary coffee processing refers to mechanical cleaning of debris from parchment coffee from the farms, and includes hulling, grading, hand picking, and packing of green coffee beans. Organic dust originates at different stages of this production line. Studies conducted in primary coffee processing factories in Papua New Guinea, Uganda, and Tanzania have shown levels of total dust exposure ranging 0.7–10 mg m^{-3}, 1–58 mg m^{-3}, and 0.24–36 mg m^{-3}, respectively (Smith *et al.*, 1985; Sekimpi *et al.*, 1996; Sakwari *et al.*, 2012). A larger number of studies in Croatia, USA, UK, Italy, and Germany have measured dust exposure in secondary coffee processing factories where polishing, roasting, and grinding take place (Zuskin *et al.*, 1979; Thomas *et al.*, 1991; Larese *et al.*, 1998; Oldenburg *et al.*, 2009). Studies in primary coffee processing factories in Uganda and Sri Lanka indicated that exposure to coffee dust is associated with acute respiratory symptoms (Uragoda, 1988; Sekimpi *et al.*, 1996), whereas an increased prevalence of chronic respiratory symptoms was reported among primary coffee factory workers in Tanzania and Papua New Guinea (Smith *et al.*, 1985; Sakwari *et al.*, 2011). A recent study in a secondary coffee processing factory in USA indicated that the workers may be at risk of developing obliterative bronchiolitis (Bailey *et al.*, 2015). However, this disease was associated with exposure to diacetyl and 2,3-pentanedione released during the coffee roasting process (Daglia *et al.*, 2007).

Dust exposure in primary processing factories varies with processes, tasks, ventilation system, type of coffee, and method of preprocessing at the farm (Smith *et al.*, 1985; Sekimpi *et al.*, 1996; Sakwari *et al.*, 2012). For instance, a study in Tanzania indicated that personal dust exposure was higher when handling dry preprocessed coffee than wet preprocessed coffee. Dry preprocessing at the coffee farm refers to a method where unpulped cherries are allowed to dry in sun under natural condition after harvesting. In the wet preprocessing method, harvested cherries are pulped immediately after harvesting, followed by fermentation and washing with clean water to remove mucilage cover. Both dry and wet preprocessing methods are used in Ethiopia.

In preparatory field visits at primary coffee processing factories in Ethiopia, we observed that more dust seemed to be generated from old processing machines compared to new machines, and that dust levels appeared to be lower in coffee factories with mechanical ventilation and good natural ventilation compared to factories without such ventilation. However, the levels of exposure have not been documented, as no study has so far been conducted in Ethiopia. Furthermore, factors that may have impact on coffee dust exposure levels have not been studied. The primary coffee processing factories in Ethiopia are different from analogous factories of Tanzania, Uganda, and Papua New Guinea where previous dust exposure measurements were conducted. Although Tanzania, Uganda, and Papua New Guinea grow both Arabic and Robusta coffee types, Ethiopia produces only Arabic coffee. Also the preprocessing method at the farms in Ethiopia is different from these countries. For example, in Tanzania, Arabica coffee is mostly wet preprocessed whereas Robusta coffee is dry preprocessed. In Ethiopia, Arabica coffee is preprocessed as dry or wet preprocessed based on the individual farmer interest. As coffee types and the processing method differ from one country to another, results from previous studies may not represent the dust exposure level in primary coffee processing factories in Ethiopia. Therefore, the aim of this study was to assess personal dust exposure and to evaluate determinants of dust exposure in primary coffee processing factories in Ethiopia.

Methods

Study area

This study was conducted from May to October 2016. Twelve primary coffee processing factories were included, four factories from each of the three regions: Addis Ababa (factories A, B, C, D); Oromia (E, F, G, H); and SNNPR (I, J, K, L).

Dust sampling strategy

The three main job groups (hand pickers, transporters, and machine room workers) had distinct characteristics in terms of tasks performed and were assumed to constitute three similar exposure groups (SEGs). The number of personal dust samples was calculated based on Rappaport and Kupper (2008) who suggested repeated samples from 5 to 10 randomly selected individuals per SEG. In each factory, five coffee workers were randomly selected for dust sampling from each of the three main job groups. Thus, 15 persons were involved from each factory, and because sampling was performed on two consecutive days for each worker, a total of 360 dust samples were taken in the 12 factories.

The machine room job group included four tasks: machine operator—monitoring the processes; mechanic work—ensure the smooth running of the machines; cleaning—clean the machine and the machine area; and feeding hopper—feeding the hopper that is located inside the machine room. The transport job group included three tasks: loading and unloading—manual transport of coffee beans; mixing—mixing reject coffee; feeding coffee—feeding hopper outside the machine room. Hand picking job group included mainly women involved in manual sorting and removal of defective and discoloured coffee beans. Some of these women sit inside the machine room and picks the coffees from the sorting tables or belts whereas others sit on the floor without table and patiently pick through piles of green coffees.

Due to sampling errors, 15 dust samples were not included in the analysis: 2 samples due to pump failure, 2 samples were taken from a person listed as a transporter but who practised presently as a supervisor, 6 samples were intentionally exposed to dust by the workers and 5 samples were damaged while sampling.

Dust sampling and analysis

Personal dust samples were taken in the workers breathing zone using 25-mm three piece, closed-faced conductive cassettes (Millipore MAWP 025 AC) with a cellulose acetate filter (Millipore AAWP02500) attached to Side Kick Casella pumps with a flow rate of 2 l min^{-1} (Occupational Safety and Health Administration, 2014). This sampling head has the same geometry (except for the cassette diameter) and orifice diameter as the 37 mm three-piece cassette used for 'total' dust sampling, and has also been assumed to sample 'total' dust at a flow rate of 2 l min^{-1} (Skaugset *et al*., 2013). The pumps were paused during lunch breaks. Full-shift exposure measurements were conducted on randomly chosen days of the week and repeated sampling was conducted the next day. Data collection took 4–6 days in each factory. The mean sampling time was 410 min with standard deviation 43 min and range of 246–494 min. Specific task duration was not recorded. During sampling, the pumps were checked every second hour. Field blanks were used to correct for any weight changes during sampling. After sampling, the cassettes were capped and transported as hand luggage by aeroplane to the laboratory in a box suitable to prevent damage or disturbance.

The dust samples were analysed gravimetrically using a standard microbalance scale AT261 Mettler Toledo with a detection limit of 0.01 mg m^{-3} in the accredited laboratory SINTEF MOLAB in Norway. The results obtained in this work were compared to the Norwegian Occupational Exposure Limit (OEL) for organic total dust of 5 mg m^{-3} (Norwegian Labour Inspection Authority, 2015).

Determinants of exposure

An observational checklist to collect information about possible determinants of dust exposure was filled in by the principal investigator during the sampling days.

The checklist included task-related determinants for machine room workers (machine operator work, mechanic work, feeding hopper, and cleaning) and for transport workers (loading and unloading, mixing coffee, and feeding coffee). The major job task performed by the respective workers was recorded during the sampling day to be linked with the associated dust sample.

The checklist also included factory-related, dichotomized determinants such as the design of the machineries; hopper, huller, and graders (open or closed top); the production rate (less or more than 50 tonnes per day); type of preprocessing method that had been used before the coffee entered the factory (dry or wet preprocessing method); mechanical ventilation system (present or absent); pouring method (pouring coffee to the hopper or ground (vigorously pouring coffee from a dropping height or gradually poured from short height), and natural ventilation [adequate ventilation with the windows and openings area greater than or equal to 10% of the floor area of the machine room or inadequate ventilation with the windows and openings area less than 10% of the floor area of the machine room (Nemerow *et al.*, 2009)].

Statistical analysis

The distribution of dust exposure levels was skewed and therefore ln-transformed before analysis. The results were described using arithmetic mean, geometric mean (GM), and geometric standard deviation. Independent *t* tests were used to test differences within the potential dichotomous exposure determinants. A one-way ANOVA was performed to compare the GM of personal total dust exposure level between main job groups and between tasks. Tukey honest significant difference tests were used to explore the difference between each job group and Games–Howell *post hoc* tests were used for tasks when equal variances assumption was not met.

Two separate linear mixed effect regression models were developed to identify significant determinants for personal total dust exposure among the machine room workers and the transport workers, respectively. We developed separate models for these job groups because they were mainly working in different rooms/areas. In the random and mixed-effect models, the ln-transformed personal total dust exposure level was used as the dependent variable. In the random model, employee and factory were entered as random effects. In the mixed-effect model, possible factory and task-related determinants (*Det*) with significance value $P \leq 0.2$ in preparatory univariate analysis were entered as fixed effects, and employee and factory were entered as random effects. The task machine operator work was the reference category in the model for machine room workers whereas loading and unloading was the reference task category for the transport workers. The final model contained only determinates with *P*-value ≤ 0.05.

The linear mixed model is given as (van Tongeren *et al.*, 2000; Rappaport and Kupper, 2008)

$$Y_{ifjk} = ln\left(X_{ifjk}\right) = \mu_i + \sum_{l=1}^{p} \alpha_{il} Det_{ifl} + \gamma_i f + \beta_i f_j + \varepsilon_{ifjk}$$

for $i = 1, \ldots, g$ denotes group; $f = 1, \ldots, F$ denotes factory (same number of factories for each group); $j = 1, \ldots, n_{if}$ denotes worker within group * *AND* * factory; $k = 1, \ldots, n_i fk$ denotes measurements within worker (and within group/factory,) where $n_i fk$ is 1 or 2; $l = 1, \ldots, p$ denotes determinant; μ_i represents the true underlying mean of log-transformed exposure level for group *i*; Det_{ifl} represents the *l*th determinants in the *i*th group in the *f*th factory;

$\sum_{l=1}^{p} \alpha_{il}\, Det_{ifl}$ represent$_s$ the fixed effects of the *p* determinants;

$\beta_i f_j$ is the random effect of the worker within group and factory and $\gamma_i f$ is the random effect of the factory; ε_{ifjk} is the random error of the *j*th worker in *i*th group in the *f*th factory on the *k*th measurements. X_{ifjk} represents the exposure level on the *k*th measurements for *j*th worker in *i*th group in the *f*th factory and Y_{ifjk} is the natural logarithm of the individual measurements X_{ifjk}.

Variance component structure was used in the model. Explained within-worker (wwδ), between-worker (bwδ), and between-factory (bfδ) variances, respectively, were calculated as the percentage change in the respective variances between the random and the mixed-effects models. Total variance explained by the fixed effects was calculated as the percentage change in the sum of the three variance components between the random and the mixed-effects model. The effects of the significant fixed factors in the mixed models were calculated as e^{β}, where β is the regression coefficient.

Design of huller correlated significantly with design of grader, so design of grader was dropped from the analysis. The analysis was performed using SPSS version 22 (IBM, 2013).

Ethical considerations

The study was approved by the Institutional Review Board of the College of Health Sciences of Addis Ababa University and the National Ethical Committee of the Federal Ministry of Science and Technology in Ethiopia. Permission to conduct the study was obtained from the factory managers. Written informed consent was obtained from each participant, and participation in the study was voluntary. Confidentiality was ensured by not using the names of the workers in any reports.

Results

Characteristics of the coffee factories

Ten of the 12 coffee factories were established before year 2010. All factories in Addis Ababa, except one, had a production rate more than 50 tonnes per day and more than one huller machine in the room. All coffee processing machines in SNNPR and Oromia regions had open-top design of machines and processed less than 50 tonnes per day, only coffee that had been preprocessed by the dry method. (For detail characteristics of primary coffee processing factories in Ethiopia, see Supplementary Table 1, available at *Annals of Work Exposures and Health* online).

Personal dust exposure

Personal dust exposure within the three main job groups varied considerably between the coffee factories (for details on personal dust exposure for each main job group in each factory, see Supplementary Table 2, available at *Annals of Work Exposures and Health* online). The GM dust exposure among machine room workers ranged from 4.09 to 34.40 mg m^{-3}, among transport workers from 3.51 to 24.19 mg m^{-3}, and among hand pickers from 0.26 to 5.87 mg m^{-3}. Overall the GM personal dust exposure was significantly higher (P = 0.001) for the machine room (12.54 mg m^{-3}) and transport workers (12.30 mg m^{-3}) than the for the hand pickers (1.08 mg m^{-3}). In these three groups, 84.6%, 84.1%, and 2.6% of the samples exceeded the OEL, respectively. None of the workers used any personal protective respiratory devices.

Task-related determinants

Among the machine room workers, there was no significant difference (P = 0.860) in personal dust exposure between cleaning (14.01 mg m^{-3}, n = 25); machine operator work (13.74 mg m^{-3}, n = 46); and feeding the hopper (12.68 mg m^{-3}, n = 42). Mechanic work was associated with lower exposure (1.99 mg m^{-3}), but the number of measurements for this task was low (n = 4), and the samples were taken from only one of the factories.

Among the transport workers, the highest exposure was associated with feeding coffee (GM of 18.54 mg m^{-3}, n = 12), followed by mixing coffee (16.44 mg m^{-3}, n = 36) and loading and unloading (9.68 mg m^{-3}, n = 65). The exposure when loading and unloading coffee was significantly lower than when mixing coffee and feeding coffee (P = 0.001).

Factory-related determinants

Personal total dust exposure among both machine room and transport workers was significantly increased when pouring coffee vigorously from a height in factories that had more than one huller machine in the room and when the hopper had open top (Table 1). For machine room workers also the state of the mechanical ventilation and the design of the huller had impact on dust exposure. For transport workers, a production rate with more than 50 tonnes per day was associated with a higher dust

Table 1. Factory-related determinants of total dust exposure for machine room workers and transporters in 12 primary coffee processing factories in Ethiopia.

Potential determinants	Definitions	NS	Machine room workers		Transporters	
			GM (mg m^{-3})	P-value	GM (mg m^{-3})	P-value
Process at the farm	0 = Wet preprocessed coffee	63	9.87	0.191	11.82	0.902
	1 = Dry preprocessed coffee	282	13.20		12.30	
Production rate	0 = Less than 50 tonnes day^{-1}	258	12.30	0.640	10.80	0.006
	1 = More than 50 tonnes day^{-1}	87	13.46		17.64	
Number of huller machine in the room	0 = One huller machine in the room	146	10.49	0.042	8.41	0.001
	1 = More than one huller machine in the room	199	14.30		16.12	
Pouring method	0 = Gradual pouring of coffee	32	5.05	0.001	6.55	0.039
	1 = Vigorous pouring coffee	313	14.30		12.81	
Factory establishment year	0 = New (after year 2010)	58	7.92	0.07	11.25	0.597
	1 = Old (before year 2010)	287	13.74		12.55	
Design of hopper	0 = Closed top	87	8.33	0.003	11.25	0.04
	1 = Open top	258	14.30		16.28	
Natural ventilation	0 = Adequate ventilation	116	12.06	0.789		
	1 = Inadequate ventilation	229	12.81			
Mechanical ventilation	0 = Working in a good condition	29	4.10	0.01		
	1 = Not working or absent	316	13.87			
Design of huller	0 = Closed top	116	9.78	0.033		
	1 = Open top	229	14.15			

NS = number of samples; GM = geometric mean; P-value for Independent t test, $p<0.05$.

exposure compared with production rate less than 50 tonnes per day. Ventilation system and design of huller were relevant only in the machine room, and were not considered as potential determinants for transporters as they work mostly outside the machine room.

Exposure determinant models

In the random-effect model (Table 2) that included employee and factory as random effects, the within-worker variance (day-to-day variance) was higher than the between-worker variance for both machine room workers and transporters. The between-factory variance was also high compared to the between-worker variance.

For the machine room workers, the linear mixed-effects model that included the pouring method of coffee beans and mechanic work explained about 34% of between-factory variance, and 21% of the total variance (Table 2). Vigorously pouring coffee from a dropping height was associated with 1.7 time increase in personal total dust exposure.

For the transport workers, the mixed-effects model that included pouring method of coffee beans, number of huller machine in the room, mixing coffee, and feeding the hopper explained about 83% of the between-factory variance, but considerably less of the between-worker and the day-to-day variance (Table 2). These fixed factors explained 32% of total variance in personal total dust exposure for the transporters. The result indicated that pouring coffee vigorously from a dropping height was the determinant with the highest impact on personal total dust exposure with 3.2-fold increase compared to gradually pouring coffee from a very short height. More than one huller machine in the room contributed to a 2.1-fold increase in total dust level compared to having only one huller machine in the room.

Discussion

Personal total dust exposure level varied both across the coffee factories and between the main job groups in

Table 2. Linear mixed-effect model of ln-transformed total dust levels in 12 primary coffee processing factories in Ethiopia.

Fixed factors	Machine room workers (‘Total’ dust in mg m^{-3})				Transport workers (‘Total’ dust in mg m^{-3})			
	Random-effects model β (SE)	Mixed-effects model β (SE)	Effect (e^{β})	*P*	Random-effects model β (SE)	Mixed-effects model β (SE)	Effect (e^{β})	*P*
Intercept	2.53 (0.18)	2.08 (0.30)		0.001	2.50 (0.14)	0.74(0.36)		0.05
Coffee pouring method: vigorously (1) versus gradually (0)		0.56 (0.31)	1.7	0.05		1.17 (0.34)	3.2	0.002
Mechanic work: yes (1) versus no (0)		−1.26 (0.43)	0.3	0.006				
Huller machines: more than one (1) versus one (0)						0.73 (0.17)	2.1	0.002
Mixing coffee: yes (1) versus no (0)						0.53 (0.15)	1.7	0.001
Feeding hopper: yes (1) versus no (0)						0.67 (0.26)	2.0	0.013
Variance components								
wwδ	0.32 (0.06)	0.32 (0.06)			0.49 (0.09)	0.42 (0.08)		
bwδ	0.13 (0.07)	0.08 (0.06)			0.05 (0.08)	0.04 (0.07)		
bfδ	0.32 (0.16)	0.21 (0.11)			0.18 (0.10)	0.03 (0.04)		
Explained variance by the fixed factors								
Within-worker		0%				14%		
Between-worker		38%				20%		
Between-factory		34%				83%		
Total		21%				32%		

β = regression coefficients, SE = standard error of the regression coefficients, wwδ = within-worker variance, bwδ = between-worker variance; bfδ = between factory variance; effect e^{β} = the effect contributed by each determinants; *P* = *P*-value.

the respective factories. About 84% of the dust measurements among machine room and transport workers were higher than the OEL value of 5 mg m^{-3}. The dust exposure was considerably lower for the hand pickers. A statistical exposure model including pouring method of coffee beans, number of huller machines, mixing coffee, and feeding hopper explained 32% of total variance in personal total dust exposure for the transporters. For the machine room workers, the pouring method of coffee beans and mechanic work explained about 21% of the total variance in dust exposure.

The GM personal total dust exposure among the machine room workers and the transporters in this study (12.4 mg m^{-3}) was higher than reported among comparable job groups in Tanzanian primary coffee factories (GM 2.5 mg m^{-3};(Sakwari *et al.*, 2012). The difference in the results could have several explanations. For example, dust exposure in the Tanzanian study was measured in processing both Robusta and Arabica coffee whereas in our study, only Arabica coffee was processed. Furthermore, the number of machines in the room could also be a reason for the difference in exposure. In all visited coffee factories in Ethiopia, all machines were located in one room whereas in two out of four of the studied coffee factories in Tanzania, the machines were located in different halls. Differences in machine design and practice in processing coffee might also have contributed to the difference in personal total dust exposure levels between these studies.

The range of personal total dust exposure in our study (0.12–81.61 mg m^{-3}) was broader than in primary coffee factories of Papua New Guinea [(0.7–10 mg m^{-3}; Smith *et al.*, 1985)] and Uganda [(10.8–58 mg m^{-3}; Sekimpi *et al.*, 1996)]. The difference from our study is difficult to explain, as both the Papua New Guinea and the Uganda studies reported only the range of the exposure levels, and did not include any measure of central tendency. Furthermore the Papua New Guinea study did not describe the factories in any detail, and in Uganda both Robusta and Arabic coffee were processed.

In this study, the exposure level varied across the task, which is consistent with the studies conducted in Tanzania and Papua New Guinea (Smith *et al.*, 1985; Sakwari *et al.*, 2012). In our study, feeding coffee caused the highest exposure for the transporters, which is different from the study conducted in Tanzania in which sweeping was associated with the highest personal total dust exposure (Sakwari *et al.*, 2012). Differences in how these tasks were performed might have caused such discrepancies. In our study, sweeping was carried out only for short periods, whereas feeding coffee was carried out for a long period of time.

The mixed-effect model indicated that the method of pouring coffee beans vigorously from a dropping height was the main determinant for increased personal total dust exposure for both machine room workers and transporters. Furthermore, among the transporters increased dust exposure level was associated also with feeding coffee and mixing coffee. Both these tasks are in most factories performed by vigorously pouring coffee from a dropping height, thus further enhancing the emission of dust from these tasks. Thus, the exposure models indicate that changing the pouring process could reduce personal dust exposure level in the coffee factories as it seems to contribute to a high background concentration of dust in the general working atmosphere. On the other hand, low dust exposure level was registered among hand pickers; their task does not involve vigorously pouring of coffee. In one of the primary coffee processing factory, hand pickers had highest dust exposure compared to hand pickers working in other coffee processing factories. During sampling, we observed that these hand pickers were sitting very close to the dust leaking machine, which might have increased their exposure.

Among the transporters, the fixed factors in the exposure model mainly explained the between-factory variance (83%). This seems reasonable for the two factory-related determinants, pouring method and number of huller machines, which alone explained 61% (not shown in Table 2) of the between-factory variance. The two task-based determinants, feeding hopper and mixing coffee, contribute to explain part of the within-worker variance (9%; not shown in Table 2), probably because some of the workers changed between these tasks between the two measurement days.

For machine room workers, mechanic work was the only task identified as a significant determinant in the exposure model. However, the few samples from this task were taken from a factory that had one of the lowest exposure levels. The small difference in exposure levels between the other three tasks for the machine room worker could be due to a high background concentration of dust emitted from the processing machinery. Even after adjusting for the pouring method of coffee, none of the other potential task-based determinants were found to be significant. One cannot exclude that a more refined categorization of the task-related determinants, for instance a detailed recording of time spent on the respective tasks could have explained more of the exposure variability in the exposure models.

Several previous studies have indicated that exposure to total coffee dust is likely to cause acute and chronic respiratory symptoms (Uragoda, 1988; Zuskin *et al.*, 1988; Larese *et al.*, 1998; Sakwari *et al.*, 2011), and our study indicated that machine room workers and transporters are exposed to even increased levels of coffee dust. Despite this fact, almost none of the workers used proper personal protective devices to reduce dust exposure. Hand pickers had a local piece of cloth to cover their nose and mouth, which will protect them from dust exposure. The reason why workers did not use personal protective device needs to be studied in the future.

As far as we are aware, this is the first study of personal dust exposure that has been conducted in primary coffee processing factories in Ethiopia. The results are believed to be representative for coffee production workers in general in Ethiopia. Repeated and a relatively large number of samples were taken among a well-decided number of workers. Furthermore, the factories included in this study were representative of primary coffee processing factories in the country in terms of size, machine type, type of coffee being processed, and design of the factory.

We did sampling with a recognized dust sampling method. However, the closed-face cassettes are known to underestimate the inhalable dust levels, especially for large particles size (Martin and Zalk, 1998; Harper and Muller, 2002; Görner *et al.*, 2010). Because the coffee processing involves a lot of manual tasks including carrying sacks on shoulder, we chose this method, to protect the filters better than if other sampling heads were used. They were also cost effective.

Conclusion

About 84% of the dust samples among machine room and transport workers in primary coffee processing factories of Ethiopia were above the occupational exposure limit value. Pouring coffee beans vigorously from a dropping height was the main determinant for increased personal dust exposure level. Proper dust control measures are necessary to reduce the dust exposure.

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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Conflicts of Interest

The authors declare that they have no competing interest.

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