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Personal Exposure to Dust and Endotoxin in Robusta and Arabica Coffee Processing Factories in Tanzania

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Introduction: Endotoxin exposure associated with organic dust exposure has been studied in several industries. Coffee cherries that are dried directly after harvest may differ in dust and endotoxin emissions to those that are peeled and washed before drying. The aim of this study was to measure personal total dust and endotoxin levels and to evaluate their determinants of exposure in coffee processing factories.

Methods: Using Sidekick Casella pumps at a flow rate of 2l/min, total dust levels were measured in the workers' breathing zone throughout the shift. Endotoxin was analyzed using the kinetic chromogenic Limulus amebocyte lysate assay. Separate linear mixed-effects models were used to evaluate exposure determinants for dust and endotoxin.

Results: Total dust and endotoxin exposure were significantly higher in Robusta than in Arabica coffee factories (geometric mean 3.41 mg/m^3 and 10 800 EU/m^3 versus 2.10 mg/m^3 and 1400 EU/m^3, respectively). Dry pre-processed coffee and differences in work tasks explained 30% of the total variance for total dust and 71% of the variance for endotoxin exposure. High exposure in Robusta processing is associated with the dry pre-processing method used after harvest.

Conclusions: Dust and endotoxin exposure is high, in particular when processing dry pre-processed coffee. Minimization of dust emissions and use of efficient dust exhaust systems are important to prevent the development of respiratory system impairment in workers.

Keywords: coffee dust; coffee processing factories; endotoxin; exposure determinants

INTRODUCTION

Globally, coffee production employs large numbers of workers. In developing countries, most coffee factory workers are involved in coffee curing, which is the primary process in coffee production. Arabica and Robusta are the two major types of coffee making up 99% of the coffee available on the global market. These two types of coffee are usually pre-processed at the farms using either a wet or dry process. East African Arabica coffee is normally pre-processed using the wet method in which the coffee cherries are depulped in a machine using water. The beans are fermented for 12–36 h, washed, and then dried on a wire mesh above the ground for 5–10 days, depending on the weather conditions. The dried parchment coffee is then transported to the factories for processing. At the end of the season, the last of the Arabica coffee harvest at the farms is dry pre-processed and sent to the factories as dried cherries. In contrast, Robusta coffee is dry pre-processed, in which the coffee cherries are dried directly after harvesting without

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peeling off the cherry cover. The coffee cherries are spread in a 10-cm thick layer on the ground and are heaped together at night and spread again each morning for 10–25 days, depending on the weather conditions (Mutua, 2000; Silva *et al.,* 2000). The dried cherries are then transported to the factories for processing (Fig. 1).

At the factory, the coffee is hulled to obtain green coffee beans (GCB). This process removes the hard cover (pericarp, mesocarp, and endocarp), and the beans are sorted by size using graders; sorted by weight using gravity tables or catadors; bulked to get a homogeneous mixture; and then packed for transportation. Damaged and discolored coffee beans may also be removed manually by hand-picking. Secondary coffee processing (coffee manufacturing), which mainly takes place in the importing countries, involves cleaning the GCB and roasting the beans (Reynold, 1979).

Organic dust exposure is a common cause of respiratory and allergy problems among workers in various agricultural industries (Zuskin *et al.,* 1989; Golec, 2006; Smit *et al.,* 2006). Total dust exposures have been measured in primary coffee processing factories (Smith *et al.,* 1985; Sekimpi *et al.,* 1996) as well as secondary coffee processing factories. Exposure to endotoxin has been studied in several industries associated with organic dust exposure, such as the food industries (Zock *et al.,* 1995; Dutkiewicz *et al.,* 2002; Ingalls, 2003), but not in primary coffee processing factories.

Dust exposure in coffee factories may lead to development of respiratory symptoms, lung and airway diseases, and allergies (Figley and Rawling, 1950; van Toorn, 1970; Karr *et al.,* 1978; Zuskin *et al.,* 1985, 1993; Larese *et al.,* 1998; Oldenburg *et al.,* 2009). A study conducted in Arabica and Robusta factories in Uganda reported a higher prevalence of cough and dyspnea among coffee workers compared with control group (Sekimpi *et al.,* 1996). Oldenburg *et al.* (2009) suggested that workers handling Brazilian Arabica coffee reported a 2-fold increase in symptoms compared with when handling Robusta coffee (Oldenburg *et al.,* 2009).

Several studies have described determinants for both dust and endotoxin exposure in grain farmers, and in other agricultural industries. The determinants for exposure differ with facility, raw materials used, weather conditions, activities, and processes (Preller *et al.,* 1995; Wouters *et al.,* 2006; Halstensen *et al.,* 2007; Spaan *et al.,* 2008). To date, exposure determinants have not been investigated in coffee processing factories. Identification of significant determinants is considered to be important in determining where the introduction of control measures will be effective in reducing exposure levels.

This study is part of a larger project in which we have previously shown a higher prevalence of cough with sputum and chest tightness among workers in primary coffee factories (Sakwari *et al.,* 2011). The aim of this study was to measure total dust and endotoxin exposure levels and to evaluate their determinants of exposure during processing of Robusta and Arabica coffee.

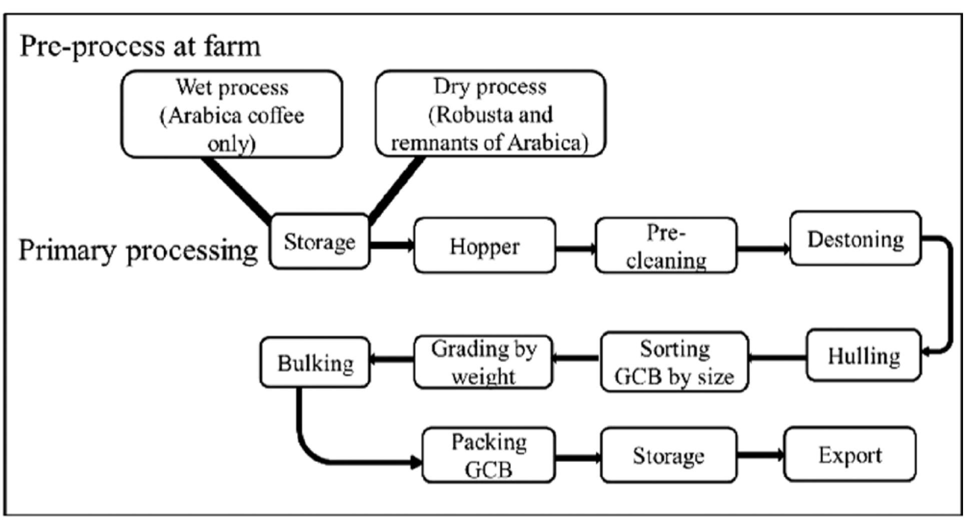

Fig. 1. Coffee processing stages in Tanzania; from farm to export.

METHODS

Study setting

This study was conducted in the Kilimanjaro and Kagera regions; two factories were selected from each region. The Kilimanjaro factories (factories A and B) produce about 5000 tonnes each of Arabica GCB per season. Factory A was established in 1997 with relatively new machinery and has approximately 45 production workers. Factory B was established in 1920 and has old machinery with about 55 production workers. The factories in Kagera in northwest Tanzania (factories C and D) process mainly dried Robusta cherries; they produce 6500 and 19 500 tonnes per season, respectively. Factory C had 30 production workers and factory D had 65 production workers.

When selecting the factories our aim was to cover old factories and newer factories as well as the two main types of coffee. Prior to our first visit, we had no information on the exposure and health of the workers.

Details about factories A and B as well as the activities involved in coffee processing have been described elsewhere (Sakwari *et al.,* 2011). Factory C was established in 1935, and the currently used production machines are from 1996–1997. The hopper and pre-cleaners are in hall 1, and the hullers and gravity table are in hall 2. Bulking and packing machines are located in an extended area of hall 2. The factory has natural ventilation through door openings and wide open windows. The gravity table has an overhead exhaust hood, which conveys dust to the husk storage tank.

Factory D was established in 2005 with machines made in 1987 and 1986; all machines are located in the same hall. Ventilation occurs naturally through grid blocks, openings along the roof and two wide open doors.

Participants

In this study, exposure data were collected in three time periods: November–December 2008 (period 1), November 2009 (period 2), and in September–December 2010 (period 3) (Table 1).

Production workers from all sections of the coffee factories were eligible for inclusion in personal dust sampling during the day shift. Working hours were from 07:00 to 18:00. A fraction of the production workers from each factory were selected for dust sampling. The majority of the participants worked with similar tasks each day; hence, few workers had repeated samples for different tasks.

In the first sampling period, participants were selected by inviting the workers with odd numbers in the personnel lists in factory A ($n = 22$); in factory B, the workers were selected randomly from the section leaders' lists ($n = 23$). In the second and third sampling periods, a group of workers were selected randomly for dust sampling ($n = 20$, 19, 18, and 8 from factories A, B, C, and D, respectively) (Table 1).

Dust sampling and analysis

Personal total dust sampling was performed throughout the work shift in the breathing zone of the workers using Sidekick Casella pumps at a flow rate of 2 l/min. The pumps were connected to 25-mm three-piece, conductive cassettes with a cellulose acetate filter in the first period and 37-mm three-piece Millipore plastic cassettes with a polycarbonate filter in the second and third periods. Sampling time had an arithmetic mean of 367 min, with a range of 116–515 min for factory A, 533 (240–695) for factory B, 459 (300–583) for factory C, and 522 (473–583) for factory D. Total dust samples collected in 2008 were analyzed gravimetrically using a microbalance scale (AT261 Mettler-Toledo Inc., Columbus, Ohio) with a detection limit of 0.01 mg/m^3 in the Eurofins laboratory in Denmark. Samples from 2009 and 2010 were analyzed in the Lund University Medical Laboratory in Sweden using a similar microbalance scale. There was no difference in weight of the blank filters after transport to Tanzania and back to the original laboratory.

Table 1. Data collection periods in the primary coffee processing factories.

Factory	Period 1		Period 2		Period 3	
	Dust	Endotoxin (pilot)	Dust	Endotoxin	Dust	Endotoxin
	Ns (Nw)	Ns (Nw)	Ns (Nw)	Ns (Nw)	Ns (Nw)	Ns (Nw)
A (Kilimanjaro)	22 (22) cc, cac	5 (5) cc, gff	33 (20) mc, pf	33 (20) mc, pf		
B (Kilimanjaro)	23 (23) cc, cac				47 (19) mc, pf	47 (19) mc, pf
C (Kagera)					60 (18) mc, pf	60 (18) mc, pf
D (Kagera)					10 (8) mc, pf	10 (8) mc, pf

Ns, number of samples; Nw, number of workers; cc, conductive cassette (25 mm); cac, cellulose acetate filters (0.8-µm pore size); mc, Millipore cassettes (37 mm); gff, glass fiber filters (0.2-µm pore size); pf, polycarbonate filters.

When loose dust was detected in the filter cassettes, the cassettes were described as overloaded; both loose dust (dust not attached to the filter) and dust on the filters was weighed. A total of 34 filters were marked as overloaded by the laboratory; of these, 10 filters were from the first sampling period, and the remainders were from the third sampling period.

Endotoxin sampling and analysis

In 2008, sampling of endotoxin was performed in a pilot study using glass fiber filters (Whatman GF/A) with 0.2-µm pore size in the 25-mm three-piece conductive cassettes ($n = 5$), whereas in 2009–2010, endotoxin sampling was performed using the same filters as those used for total dust sampling, i.e. polycarbonate filters with 0.8-µm pore size in the 37-mm three-piece cassettes. Sampling in the third period was carried out over 12 days in factories B and C, and over 2 days in factory D.

Filters from the first and second periods were kept cold at about 4°C until arrival in Norway, and then frozen until the day of analysis. Filters from the third period were kept frozen after the sampling day and were transported to Norway as hand luggage packed with freeze packs to maintain a low temperature. Travel time was approximately 29 h for the second period and 16 h for the first and third periods.

Endotoxin samples from first period were analyzed at the National Institute of Occupational Health laboratory in Oslo, and those from the second and third periods were analyzed at Lund University Medical Laboratory.

The glass fiber filters were immersed in nonpyrogenic water with 0.05% Tween-20 and were shaken on a rotary shaker for 1 h. Endotoxin extracts were analyzed by kinetic chromogenic Limulus amebocyte lysate (LAL) Assay in a similar procedure as that described by Douwes *et al.* (1995).

The samples on polycarbonate filters from the second and third sampling periods were also analyzed using the kinetic chromogenic LAL test (Lane *et al.*, 2004). The results were given as endotoxin units per cubic meter (EU/m^3).

Potential determinants

Potential dust and endotoxin exposure determinants were grouped as task or factory-related. Task-related determinants included tasks performed at the time of sampling, i.e. feeding coffee to the hopper, monitoring the hullers, monitoring the gravity table, handling husks, bulking the coffee, storing green coffee bags, or sweeping (Table 2).

The factory-related determinants included: the ventilation mechanism—natural versus natural with mechanical aid; the design of the hopper, huller, and graders—open or closed tops; the production rate—more or less than 50 tonnes per day; practices in processing—whether or not at any stage coffee was poured vigorously from a dropping height. Processing at the farm, dry pre-processed coffee or wet pre-processed coffee, and type of coffee being hulled, Arabica or Robusta, were also included as possible determinants (Table 3). All the determinants were dichotomized (0/1) in the statistical analyses.

Information on the characteristics of the factory, practices in processes, design of machines, and task performed was obtained by observing the work site during sampling and interviews with the factory engineers. Production rate was calculated based on the amount of coffee produced during the particular research period. Sampling period was not included as a determinant because two of the factories were only sampled during one period.

Statistical analysis

IBM SPSS version 19 for Windows was used. The exposure data were skewed and were therefore $\log_e$-transformed before analysis. The correlation between total dust and endotoxin was calculated by the Pearson correlation test. Independent *t*-tests were used to compare differences within the potential exposure determinants.

Linear mixed-effects models were used to determine explanatory factors for total dust and endotoxin exposure. Log_e-transformed values for total dust or endotoxin were entered as dependent variables in the model. The individual worker and factory were entered as random effects. The possible determinants with significance value $P \leq 0.2$ in univariate analysis were entered as fixed effects in the model in two stages, starting with factory-related determinants. The factory-related determinants with a *P*-value < 0.2 were retained in the model before adding the task-related determinants. In the final model, factors with significance of ≤ 0.2 were retained. The effect contributed by each determinant was calculated as e^{β}, where β is the regression coeffient for the respective determinant.

RESULTS

A total of 195 samples were collected for total dust and 155 samples for endotoxin. Two samples were not analyzed: one sample due to pump failure and the other filter was accidentally dropped from a height.

Exposure to total dust

Personal total dust exposure (n = 193) had geometric means (GM) of 1.90, 2.27, 3.36, and 3.82 mg/m^3, in factories A, B, C, and D, respectively (Table 2). The range of individual total dust exposure was 0.24–36 mg/m^3. Of these samples, 17% exceeded the occupational exposure limit of 5 mg/m^3 for total organic dust set by the Norwegian Labour Inspection Authority (Norwegian Labour Inspection Authority, 2010). Tanzania has no occupational exposure limit value; hence, we compared the exposure to the limit in the collaborating country.

Dust exposure levels varied with the task performed (Table 2). The task with the highest dust exposure level was sweeping (GM = 4.74), with a highest individual value of 36 mg/m^3. Tasks with less contact with coffee beans such as sampling, machine repair, and handling of parchment coffee had significantly lower exposure to dust than the other tasks and were used in further analyses as a reference group.

Dust exposure was significantly higher in Robusta coffee factories (GM 3.42 mg/m^3) than in Arabica factories (GM 2.10 mg/m^3, P = 0.001) and when handling dry pre-processed coffee (GM 3.68 mg/m^3) compared with wet pre-processed coffee (GM 1.90 mg/m^3) (Table 3). Open-top machines and pouring coffee vigorously from a dropping height were associated with higher dust levels than closed top and pouring gradually from a very short height, respectively (GM: 3.40 versus 1.92 mg/m^3 and 3.36 versus 2.24 mg/m^3) (Table 3).

There were no significant differences in total dust exposure between factories with natural ventilation aided by extraction hoods and those without, or between factories with one of the machines in

Table 2. Personal total dust and endotoxin levels in the coffee factories by factory, coffee type, and tasks.

Variable	Total dust (mg/m^3)					Endotoxin (EU/m^3)				
Factory	Nw	Ns	AM	Range	GM (GSD)	Nw	Ns	AM × 10^4	Range	GM ×10^4 (GSD)
Factory A	34	55	3.75	0.24–27.95	1.90 (3.15)	24	38	0.54	42–75 083	0.14 (5.22)
2008	22	22	1.49	0.32–12.00	0.99 (2.14)	5	5	0.22	220–6633	0.12 (3.44)
2009	20	33	4.27	0.24–27.95	2.10 (3.48)	20	33	0.58	42–75 083	0.14 (5.58)
Factory B	37	69	3.62	0.25–36.00	2.27 (2.51)	19	47	0.21	167–8833	0.15 (2.40)
2008	22	22	4.44	0.25–36.00	1.54 (3.71)					
2010	19	47	3.24	0.51–12.82	2.73 (1.83)	19	47	0.21	167–8833	0.15 (2.40)
Factory C	18	59	3.63	1.20–6.67	3.36 (1.51)	18	59	1.41	1913–46 964	1.08 (2.17)
Factory D	8	10	4.13	1.74–6.46	3.82 (1.56)	8	10	1.24	3389–22 080	1.05 (1.88)
Total	97	193	3.69	0.24–36.00	2.50 (2.44)	69	154	0.82	42–75083	0.35 (4.36)
Coffee type										
Arabica	71	124	3.69	0.24–36.00	2.10(2.79)	43	85	0.36	42–75083	0.14(3.58)
Robusta	26	69	3.70	1.20–6.67	3.42(1.52)	26	69	1.39	1913–46964	1.08(2.12)
Task-related determinants[a]										
Work in hopper	29	53	4.18	0.77–14.06	3.68(1.65)**	23	47	1.36	672–75083	0.68(3.77)**
Work in huller	8	28	3.03	0.51–6.57	2.45(2.06)**	6	25	1.12	978–27585	0.64(3.29)**
Work at gravity table	6	11	6.56	0.46–27.95	3.91 (2.93)**	6	11	0.72	42–13098	0.44(5.13)**
Work in husks	6	12	3.53	0.76–14.46	2.35(2.44)**	5	10	0.55	327–22769	0.32(3.29)**
Bulking	11	25	2.72	0.79–5.88	2.42(1.66)**	9	23	0.41	284–16875	0.22(3.30)**
Packing and Storage	22	29	3.06	0.43–12.82	2.31(2.18)**	19	26	0.39	167–13197	0.21(3.71)*
Sweeping	10	10	9.52	1.70–36.00	4.74(3.19)**	3	3	0.07	502–832	0.07(1.31)
Sampling/machine repair[b]	11	11	0.51	0.25–1.00	0.46(1.58)					
Handling parchment coffee[b]	11	14	2.40	0.24–12.80	1.31(3.01)	7	9	0.10	72–4842	0.05(3.73)

Nw, number of workers who carried the sampling device; Ns, number of samples; mg/m^3, milligrams/cubic metre; EU/m^3, endotoxin units per cubic metre; AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation.
[a]Some workers have participated in more than one task during the study period.
[b]The two groups were combined to make a reference group.
*$P < 0.05$.
**$P < 0.01$.

Table 3. Possible factory-related determinants for dust and endotoxin exposure levels in four coffee factories.

Determinant	Definition	Factory	Nd	Log_e total dust (mg/m^3)	*P*-value	Ne	Log_e endotoxin ($\times 10^4$ EU/m^3)	*P*-value
Ventilation mechanism	0 = Natural ventilation with exhaust hoods	B	69	2.27	0.281	47	0.15	0.001
	1 = Natural ventilation	A, C, D	124	2.63		107	0.52	
Open-top machines	0 = Closed top	A, B, C	104	1.92	0.001	73	0.21	0.001
	1 = Open top	A, B, C, D	89	3.40		81	0.54	
Practices in processes	0 = Gradual pouring of coffee	A, B, C	141	2.24	0.001	108	0.31	0.110
	1 = Vigorous pouring of coffee	B,C,D	52	3.36		46	0.47	
More than one machine in one room	0 = One machine	B	69	2.27	0.281	47	0.15	0.001
	1 = More than one machines	A,C,D	124	2.63		107	0.52	
Production rate	0 = Less than 50 tonnes per day	A,B,C	183	2.44	0.123	144	0.67	0.001
	1 = Above 50 tonnes per day	D	10	3.82		10	1.05	
Process at farm	0 = Wet pre-processed	A,B	113	1.90	0.001	74	0.11	0.001
	1 = Dry pre-processed	A,C,D	80	3.68		80	1.00	
Type of coffee	0 = Arabica	A, B	124	2.10	0.001	85	0.14	0.001
	1 = Robusta	C, D	69	3.42		69	1.08	

Nd, number of dust samples; Ne, number of endotoxin samples.

a separate room compared with those in which all machines are located in one room.

Samples from Arabica factories (A and B) were taken over two periods. The dust exposure differed between the two periods in factory A ($P < 0.001$); there was a sampling day in which dry-pre-processed Arabica was hulled. In factory B, there was no significant difference in mean levels of samples between the two periods (Table 2).

Exposure to endotoxin

Individual endotoxin exposure (n = 154) ranged between 42 and 75 083 EU/m^3, whereas GM for the different tasks ranged from 700 to 6800 EU/m^3 (Table 2). There were significant differences in exposure levels for endotoxin between the factories. All the samples, except two, had higher levels than the health-based recommended exposure limit of 90 EU/m^3 (Health Council of the Netherlands, 2010). Endotoxin exposure was significantly higher when handling Robusta coffee compared with Arabica coffee, as well as when handling dry pre-processed compared with wet pre-processed coffee. A decreasing trend in endotoxin exposure levels was observed along the flow line (Table 2). Significant differences in endotoxin exposure were observed in most of the tested determinants (Table 3).

Correlations

Total dust levels correlated significantly ($P < 0.001$) with the endotoxin levels within the different factories (Pearson correlation coefficient; r = 0.83, 0.73, 0.66, and 0.67; for factories A, B, C, and D, respectively). There was a significant correlation also when pooling all samples from all factories (r = 0.62, $P < 0.001$) (Fig. 2).

Exposure determinant model

In the random effect model, the between-worker variance was higher than within-worker variance for both dust and endotoxin (Table 4). For endotoxin, the between-factory variance was the highest variance component, whereas it was lowest for total dust.

The linear mixed-effects model that included dry pre-processed coffee as a fixed effect (Model 1) explained 50% and 90% of the between-factory variance for total dust and endotoxin, respectively (Table 4). None of the other factory-related determinants entered the models.

When, in addition to dry pre-processed coffee, the task-related determinants were also added, work in the hopper, work in the gravity table, and sweeping entered the model for total dust exposure (Model 2) (Table 4); these factors mainly explained the between-worker variance and 30% of the total variance in total dust exposure. About 71% of the total variance in endotoxin exposure was explained by dry pre-processed coffee, work in the hopper, huller, and husks (Table 4). Furthermore, the task-related determinants also had the most effect on the between-worker variance for endotoxin. Dry pre-processed coffee was the only fixed factor that explained part of the within-worker variance for both total dust (6%) and endotoxin (14%). Dry pre-processed coffee

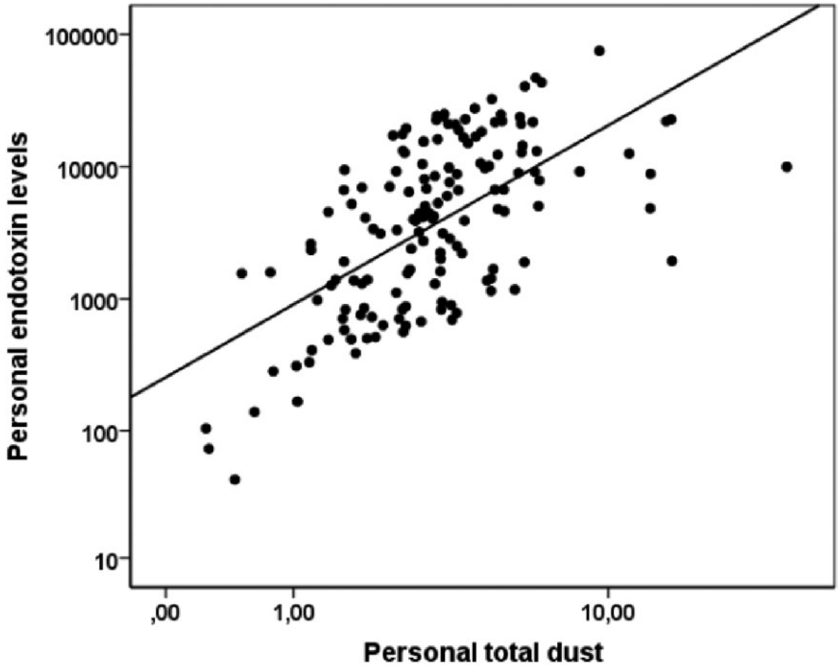

Fig. 2. Correlation between total dust levels (in mg/m^3) and endotoxin levels (in EU/m^3) in four coffee factories ($r = 0.62$, $P < 0.001$, $n = 149$).

Table 4 Linear mixed-effects model of $\log_e$-transformed total dust and endotoxin levels in four primary coffee processing factories.

	Personal total dust (mg/m^3)				Endotoxin (EU/m^3)			
	Random effects modelβ (SE)	Mixed-effects model 1β (SE)	Mixed-effects model 2β (SE)	Effect (e^{β})	Random effects mode lβ (SE)	Mixed-effects model 1β (SE)	Mixed-effects model 2β (SE)	Effect (e^{β})
Intercept	0.91 (0.17)	1.40 (0.17)**	3.29 (0.43)**		8.13 (0.62)	9.03 (0.25)	11.58 (0.51)**	
Dry pre-processed coffee[a]		0.89 (0.19)**	0.91 (0.18)**	2.5		2.05 (0.27)	1.97 (0.24)**	7.2
Work in the hopper			0.53 (0.16)**	1.7			1.04 (0.19)**	2.8
Work at the huller			–				0.87 (0.27)**	2.4
Sweeping			1.25(0.27)**	3.5			–	
Work in husks			–				1.15 (0.34)**	3.2
Work in gravity table			0.38 (0.26)	1.5			–	
Wwδ^2	0.33 (0.05)	0.31 (0.06)	0.31 (0.05)		0.58 (0.09)	0.50 (0.09)	0.50 (0.09)	
Bwδ^2	0.53 (0.12)	0.47 (0.07)	0.32 (0.09)		0.69 (0.19)	0.47 (0.17)	0.22 (0.12)	
Bfδ^2	0.08 (0.10)	0.04 (0.10)	0.03 (0.06)		1.47 (1.26)	0.14 (1.17)	0.08 (0.09)	
% of variance explained by the fixed effects		13%	30%			58%	71%	

Abbreviations: Wwδ^2, within-work variance; Bwδ^2, between-worker variance; Bfδ^2, between-factory variance.
[a]Coffee cherries that are dried directly after harvest. This includes all Robusta coffee and remnants of Arabica coffee at end of season
**$P < 0.01$.

was the determinant with the highest impact on endotoxin exposure (7.2-fold increase compared with wet pre-processed coffee), but it had considerably less impact on total dust exposure (2.5-fold increase).

When dry pre-processed coffee was included as a fixed factor, the type of coffee (Arabica versus Robusta) was not retained in the models for total dust or for endotoxin. When we excluded the data from the pilot study that had been analyzed in a different laboratory [endotoxin data (n = 5) from the first sampling period], the determinants in the exposure models did not change significantly.

DISCUSSION

Endotoxin levels in the Robusta and Arabica coffee factories were considerably higher than the health-based recommended occupational exposure level of 90 EU/m^3 (Health Council of the Netherlands, 2010). All endotoxin samples, except two, were above this level. About 17% of the personal total dust samples exceeded the recommended Norwegian occupational exposure limit for total organic dust (Norwegian Labour Inspection Authority, 2010). The exposure models with dry pre-processed coffee, work in the hopper, huller, and gravity table explained 30% of the total variances of total dust, whereas 71% of the total variance in endotoxin was explained by the model that included dry pre-processed coffee, and work in hopper, huller, and husks.

To our knowledge, only two previous studies have reported dust levels in primary coffee processing factories. In these studies, total dust ranged between 0.7 and 10 mg/m^3 in Papua New Guinea (Smith *et al.,* 1985) and 10.8 and 58 mg/m^3 in Uganda (Sekimpi *et al.,* 1996). Mean values for total dust were not given in those studies; hence, we cannot compare further. Other exposure studies in the coffee industry have been performed in secondary factories in Croatia, the USA, United Kingdom, Italy, and Germany (Zuskin *et al.,* 1979; Jones *et al.,* 1982; Thomas *et al.,* 1991; Larese *et al.,* 1998; Oldenburg *et al.,* 2009), where the difference in the dust content might be due to the different stage in coffee processing. The dust from primary coffee processing has been reported to contain a higher percent of larger, coarse particles from the husks (Smith *et al.,* 1985), which may be different from the dust in secondary processing. However, the range of total dust levels in secondary coffee factories is reported to be comparable to our study (0.07–63 mg/m^3; Zuskin *et al.,* 1979; Jones *et al.,* 1982; Thomas *et al.,* 1991; Larese *et al.,* 1998).

In the linear mixed-effects model, a 3.5-fold increase in total dust was attributed to sweeping, a 2.5-fold increase to dry pre-processed coffee, and a 1.7-fold increase was attributed to work in the hopper. In the study from Papua New Guinea, a 10-fold increase of total dust was attributed to husk sorting and operation of packing machines (Smith *et al.,* 1985). Differences in determinants between these studies may be due to different reference groups and to the design of the machines, but this information was not provided in the Papua New Guinea study. Studies in agricultural industries (Preller *et al.,* 1995; Halstensen *et al.,* 2007; Spaan *et al.,* 2008) have identified analogous determinants to our study: type of grain or crop, and tasks.

The endotoxin levels had very high variability (42–75 083 EU/m^3, GM 2600 EU/m^3), which is analogous to the high variability reported in other agricultural processing industries such as potato processing factories (0.5–62 227 EU/m^3, GM 279 EU/m^3), food factories (7.4–5363 EU/m^3), and grain processing factories (95–149 060 EU/m^3, GM 360 EU/m^3) (Zock *et al.,* 1995; Ingalls, 2003; Spaan *et al.,* 2006). The higher levels of endotoxin in Robusta factories compared with Arabica factories might be due to different farm pre-processing methods. Arabica is mostly wet pre-processed and dried on a wire mesh, whereas Robusta is dry pre-processed and dried on the ground. Mould growth has been reported on dry pre-processed Robusta coffee (Bucheli *et al.,* 2000). Varieties of microorganisms such as Gram-negative bacteria (Silva *et al.,* 2000; Avallone *et al.,* 2001) and moulds (Suarez-Quiroz *et al*., 2004) have also been isolated from both dry cherries and parchment coffee. Thus, dust from both types of primary coffee processing factory may contain remains of such microorganisms.

In the linear mixed-effects model, the determinants related to increased levels of endotoxin included dry pre-processed coffee and work in the hopper, huller, and in husks but not to the design of the machine (whether open or closed), as was found in potato processing by Zock *et al.* (1995), where open rolling mill machines were associated with higher levels of endotoxin in potato processing. Dry pre-processed coffee had a considerably higher impact on endotoxin exposure than total dust. When controlling for type of pre-processing (dry versus wet) in the exposure models, the type of coffee had no effect on exposure. The results indicate that the type of pre-processing at the farms is a more important determinant of exposure than the type of coffee.

Thus, high exposure recorded during processing of Robusta is presumably because Robusta coffee is dry pre-processed, whereas most of the Arabica is wet pre-processed at the farms.

The between-worker variability was higher than the within-worker variability for both dust and endotoxin in this study. In the linear mixed-effects models, the determinants explained mainly the between-factory and the between-worker variability, which is comparable to other studies (Wouters *et al.*, 2006; Spaan *et al.*, 2008). The fact that the within-worker variability was explained to a lesser degree by the models may be due to the workers performing similar tasks from day to day.

Dust and endotoxin levels were significantly correlated. Similar correlations were found between inhalable dust and endotoxin from different types of factories such as hemp-processing (Fishwick *et al.*, 2001), coffee roasting and tea trading, rice hulling and legume processing (Spaan *et al.*, 2008). Endotoxin is not analyzed in east African laboratories and, because the samples must be kept frozen, there are practical problems related to transport to foreign laboratories. Thus, if the association between total dust and endotoxin levels is valid, high organic total dust could indicate correspondingly high levels of endotoxin. However, more studies are needed to confirm this in the coffee industry.

Sweeping was associated with high dust exposure and was a significant exposure determinant in the total dust model. Similarly, sweeping has been associated with higher dust in hemp processing (Fishwick *et al.*, 2001), and in dust exposure (3.6 times higher) and endotoxin exposure (4.4 times higher) in horse stables (Samadi *et al.*, 2009). However, in this study, sweeping was not associated with endotoxin exposure, which may be due to a low number of samples from sweeping tasks. It may also be dependent on the time and the place that needed sweeping on that particular day.

In this study, endotoxin samples from the first period (pilot) were analyzed in a different laboratory, which could introduce some variability (Chun *et al.*, 2006). However, when the data from the pilot study (n = 5) were excluded, the explanatory variables in the mixed-effects model did not change significantly.

This study was not without some limitations. We did not study microbe-derived components other than endotoxin in the samples collected. The aim of this study was to assess the level of endotoxin in coffee factories at which our previous study had shown an increased prevalence of respiratory symptoms (Sakwari *et al.*, 2011). It has been shown in other studies that exposures to organic dust in farm green waste composting plants include β(1→3)-glucan as well as bacteria, fungi spores, and moulds (Halstensen *et al.*, 2007; Cryprowski *et al.*, 2011), which have adverse health effects on the exposed individuals (Gladding *et al.*, 2003; Adhikari *et al.*, 2011). Furthermore, it has been shown that there is high correlation between endotoxin and β(1→3)-glucan (Rylander *et al.*, 1999; Gladding *et al.*, 2003), which means there is a great possibility of high levels of β(1→3)-glucan also in coffee factories.

Sampling inhalable dust by IOM cassettes collect 1.5–4 times more dust mass than total dust sampled by closed-face filters (CFC) (Martin and Zalk, 1998). The CFC samples less mass when the particle size is >30 μm (Görner *et al.*, 2010). However, the closed-face cassettes help to protect the filters in this sampling environment where a lot of manual tasks are involved, with an associated risk of disrupting the filters. The CFC samplers were also affordable.

The factories included in this study are representative for coffee processing factories in Tanzania with regard to machinery, factory size, and type of coffee being processed. Hence, our results are presumably applicable to other Tanzanian primary coffee processing factories.

CONCLUSIONS

The high levels of endotoxin in primary coffee processing may pose a respiratory health risk to the exposed workers. More efforts should be placed on reduction of coffee dust exposure in order to lower the endotoxin exposure in coffee processing. This could be achieved by focusing on the process-related determinants. Installation of exhaust hoods on hoppers, the gravity table, hullers, and in husk storage areas could reduce the amount of endotoxin and dust suspended in the air. Appropriate respiratory protective equipment should be used by all production workers during processing.

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