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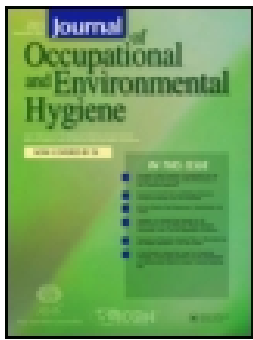
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BAKERS' EXPOSURE TO FLOUR DUST

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ABSTRACT

Introduction: We aimed to characterize bakers' personal exposure to airborne flour dust in respect to the health-related aerosol fractions inhalable, extrathoracic and thoracic dust, and to examine possible production-related determinants of dust exposure.

Methods: Sixty-eight bakers from 7 bakeries in Bergen, Norway (2009-2012) participated in the exposure assessment, comprising full-shift personal samples of inhalable dust (n=107) and thoracic dust (n=61). The relation between possible determinants and exposure was estimated using mixed effects models, while associations between the various aerosol fractions across task groups and type of bakeries were described by Pearson's correlation coefficients.

Results: Bakers overall geometric mean personal exposure to inhalable, extrathoracic and thoracic dust were 2.6 mg/m³ (95% CI: 2.0, 3.2), 2.2 mg/m³ (95% CI: 1.9, 2.7) and 0.33 mg/m³

(95% CI 0.3, 0.4), respectively. A total of 29% of the measurements of inhalable dust were above the Norwegian Occupational Exposure Limit of 3 mg/m^3 . The exposure variability of inhalable dust could not be explained by any of the examined production-related determinants, while the daily production volume explained 18% of the variance in thoracic dust. Overall, the thoracic dust represented 15% of the inhalable dust, being rather stable across the production-related determinants. The overall correlation between inhalable and thoracic dust was nevertheless moderate ($r=0.52$, $p<0.001$), with the highest correlation for craft bakers ($r=0.62$) and no correlation during dough forming ($r=0.01$).

Conclusion: Bakers are exposed to flour dust at a level that most likely represents an excess risk of developing chronic diseases of the respiratory system, and a decrease of present exposure level is imperative. Extrathoracic dust – likely the most relevant sub-fraction in respect to flour-induced sensitization and occupational rhinitis – represented the main proportion of the measured inhalable dust. The variation in correlation coefficients between the dust fractions across bakery types and task groups underlines the need of more knowledge about how these aerosol fractions are distributed across the production process and bakery types.

Keywords

Bakers' exposure to flour dust, health-based dust fractions, inhalable and thoracic dust

INTRODUCTION

The inhalable flour dust aerosol has a particle size distribution comprising extrathoracic particles that can deposit in the upper airways, tracheobronchial particles that pass the pharynx and deposit in the bronchi, and respirable dust that is able to reach the alveoli. While inhalable dust is defined as particles having an aerodynamic diameter below 100 μm , thoracic dust is defined by a penetration curve of the total airborne particles with a cut-off at an aerodynamic diameter of 10 μm and geometric standard deviation (GSD) of 1.5 (1). The site of the dusts' deposition in the respiratory system is dependent on the particle size distribution of the aerosol, again likely to determine the risk of the various health outcomes. Bakers are at an increased risk of developing rhinitis and asthma due to their occupational exposure to flour dust and related allergens (2,3). While exposure to extrathoracic dust is likely to be the most relevant sub-fraction in respect to flour-induced sensitization and development of occupational rhinitis, the thoracic dust mainly affects the lower airways.

Existing evidence suggests that nasal symptoms often precede symptoms from the lower airways, and that occupational rhinitis hence is a risk factor of occupational asthma (4,5). This concept of united airways disease, characterized by inflammation of the respiratory tract, in which asthma and rhinitis are the upper and lower respiratory tract manifestations, respectively, of the same disease process, is particular evident for high molecular weight agents, including occupational exposure to flour dust (5-8). In a previous study in bakeries included in the present study it was reported that nasal indices of inflammatory markers in nasal lavage increased with increasing exposure levels of flour dust in bakery workers (9), and that both IgE- and non-IgE-mediated occupational rhinitis were strongly associated with asthma symptoms (8). However,

only total dust was measured. Selecting the appropriate exposure measure, i.e. extrathoracic fraction of flour dust for occupational rhinitis, is essential for doing a proper assessment of exposure-response relationships and hence risk evaluation for this end-point in flour-exposed workers.

We aimed to characterize bakers' personal exposure to airborne flour dust with respect to the health-related aerosol fractions inhalable, extrathoracic and thoracic dust. We also wanted to examine production-related determinants of dust exposure in these bakery workers that could provide important information for designing an optimal grouping strategy for a planned epidemiological study on these bakery workers' risk of flour dust-induced effects on the respiratory system.

METHODS

Bakery characteristics

The study population comprised bakers from 7 bakeries in Bergen, Norway, including two craft bakeries (A and B), four industry bakeries (bakery C-F), and one “*Soft bread bakery*” (G) (table I). The industry bakeries had a high level of automatization, produced a range of products such as bread, buns, pastries and cakes, and had a daily production of more than 50 doughs (ranging in weight between 70-270 kg). The bakers tended to be specialized in specific parts of the production performing either dough making, dough forming or baking of bakery goods. The two craft bakeries had a low level of automatization, produced the same variety of products as the industry bakeries but in lower quantities (9-20 doughs, approx. 30-70 kg each), and over the work shift the bakers rotated between dough mixing, dough forming, operating ovens and wrapping (craft bakers). The “*Soft bread bakery*” only produced “*lefse*”; a traditional soft

flatbread rolled up with a spread of butter, sugar and cinnamon. The process was mainly automated, but bakers added flour to the mixer and monitored the production along the production line. While industry bakeries operated for 24 hours a day in three 8 hour work shifts, the craft bakeries and *Soft bread bakery*” generally operated day- and evening shifts (8 hours). Since the “*Soft bread bakery*” differed from the others both in the products and production process it was handled as a separate bakery type.

Production process

The production process in a bakery can be divided into dough-handling processes (dough-making, dough-forming and cleaning), bread-handling processes (tasks related to baking of bread and pastries, packing and counterhands), and administration (placing of orders, supervising the production and customer care). The present study only included bakers involved in dough making, dough forming, and baking bread and pastries. *Dough making* involves weighing of ingredients, transfer of flour and other baking ingredients to the kneading trough (mixer) and mixing of flour with other ingredients. All these tasks can be performed in a closed system with or without local exhaust ventilation. *Dough forming* involves moulding, breaking and cutting of dough, dusting of work table (by hand, dredgers or sprinklers), forming bread, buns and rolls, and decorating the baked goods with various toppings. *Baking of bread and pastries* involves the operation of oven, and movement of the baking goods in and out of oven.

For the “*Soft bread bakery*” the production was divided into two sections; dough area and the packing area. In the dough-area the dough was mixed and formed into soft flatbread that was baked until browned and then left to dry. In the packing area some of the soft bread were packed into boxes, while some was moistened, smeared with butter, sugar and cinnamon and wrapped.

All bakers were to varying degrees also involved in cleaning of equipment or production area, and the methods used range from using an industrial vacuum-cleaner, mopping with water, dry sweeping, brushing of tables and machines by hand, and the use of pressurized air. The present study does not include measurements on extensive periodical cleaning.

Occupational exposure limits

Most occupational exposure limits (OEL) for flour dust have been established for inhalable dust, and the OELs are ranging from 0.5 mg/m³ (10) to 10 mg/m³ (11). The Norwegian OEL for inhalable flour dust is 3 mg/m³. Since it is difficult to identify a threshold for sensitizing bioaerosols such as cereal flour, several organizations have labelled it as an airway sensitizer instead of deciding on an OEL-value.

Exposure assessment

The database used in the present study consists of exposure measurements from two surveys. The largest survey was carried out by occupational hygienists from the Department of Occupational Medicine, Haukeland University Hospital, in each of the 7 bakeries during 2012 (January – April, October and November), and was part of an ongoing epidemiological cohort study of bakery workers addressing flour-induced effects of the respiratory system. The other exposure survey was carried out in 4 bakeries (bakery A, C, D and E) in the period between August 2009 and January 2010 by the bakeries' Occupational Health Service.

Sampling strategy

Each baker performed the tasks he was scheduled for during ordinary activity. In the analysis each baker were placed into the task groups dough mixing, dough forming or baking of bread and pastries. For both surveys the dust sampling devices were carried by the workers and placed

in the workers' breathing zone aiming at a full-shift sampling time of 8 hours. The exposure survey in 2012 included sampling of airborne flour dust (inhalable and thoracic dust), while the exposure survey in 2009-2010 included samples of inhalable dust only. Sampling in each bakery was conducted on 3 to 5 consecutive days depending on the number of eligible workers, covering all work shifts (day, evening and night). Since all eligible bakers working during the sampling days were invited to participate, up to 6 repeated measurements were obtained (range 1 – 6). A total of 5 bakers from two bakeries did not agree to take part in the study (participation rate 93%).

Collection of dust samples and analysis

Full-shift personal samples of inhalable and thoracic dust were collected within the breathing zone by using the pulsation-free battery-powered pumps Side Kick Casella (SKC Inc.) or PS 101 (manufactured at National Institute of Occupational Health, Oslo, Norway). In the 2012 survey parallel samples of inhalable and thoracic dust were collected.

Inhalable dust was collected by PAS6 cassettes (12,13) operated at a flow rate of 2.0 L min^{-1} using PTFE membrane filters with 25 mm diameter and pore size $3 \mu\text{m}$ (Fluoropore FSLW, Millipore). Thoracic dust was collected by thoracic cyclones (GK 2.69; BGI Instruments, Waltham, MA, USA) operated at a flow rate of 1.6 L min^{-1} using PTFE membrane filters with pore size $1 \mu\text{m}$ (Fluoropore FALP, Millipore, Cork, Ireland) on cellulose support pads (Millipore Corp., Billerica, MA, USA) in 37-mm diameter standard aerosol cassettes.

Gravimetric mass determination of dust samples

After sampling the filters were stored at room temperature until being shipped to NIOH, Oslo, Norway, for mass determination. Mass determinations of inhalable and thoracic dust samples

were performed with a Sartorius MC 5 micro balance (Sartorius AG, Gottingen, Germany). Filters, including a field blank for every 10th exposed filter, were conditioned for 5 days in a climate-controlled room (temperature $20 \pm 1^\circ\text{C}$ and relative humidity $40 \pm 2\%$). Static charging was minimized by microbalance ionizers (StaticmasterR; NRD, LLC, Grand Island, NY, USA). All dust masses were corrected by the average of 2-3 field blanks that had been weighed on the same day. The limit of detection (LOD) was defined as $3 \times \text{SD}$ of a laboratory blank that was weighed each day when exposed samples were weighed. The LOD was 0.016 mg for thoracic samples and 0.11 mg for inhalable samples. Extrathoracic dust was estimated by subtracting thoracic dust masses from the inhalable dust masses.

Determinants of exposure

To register relevant information on potential determinants of exposure in the 2012 survey (e.g. table I), we performed a walk-through survey and had a meeting with the management prior to the exposure assessment. Based on this information a questionnaire was developed that was used at the end of each shift when the sampled bakers were questioned about job tasks performed, number of mixed doughs, job organization, and use of dust reducing techniques including specific control measures related to confinement of dust generating procedures (number of silos, use of lid on mixing tub and local exhaust ventilation), and cleaning methods. For measurements of inhalable dust from the exposure survey in 2009-2010, we analyzed the exposure determinants “bakery”, “bakery type”, and “tasks” only.

Data analysis

We excluded collected samples with obvious errors including a reduction in flow rate across the sampling period of $>20\%$ (2 inhalable dust samples and 2 thoracic dust samples), and when

the pump had stopped during the sampling period (1 inhalable dust sample and 2 thoracic dust samples). We did not observe any broken or double-exposed filters.

Since plots of the exposure data indicated that the distribution was skewed to the right, log-transformed data ($\ln$) were used in the analysis. Exposure levels were presented by geometric mean (GM), geometric standard deviation (GSD), 95% confidence interval (95% CI) and range (min-max) (table II). Tests of the difference in exposure across bakery, type of bakery, production volume, various tasks, various control measures, and cleaning methods were ascertained by use of mixed effect models adjusting for repeated individual measurements (random effects) and using determinants as fixed effects (table III). The estimation in this model was based on “compound symmetry”. We ran separate models including each of the determinants at a time with a calculation of the corresponding percentage variance explained (R^2) by this determinant and the variance components between-worker ($_{BW}S^2$) and within-worker ($_{WW}S^2$). To test for a possible multivariate effect of the determinants we also ran a forward stepwise model including variables with a p-value of less than 0.20 in the univariate analysis. Information on production volume, control measures and cleaning methods was only available for the exposure survey in 2012, and the analysis of these determinants were therefore restricted to this survey.

Associations between production volume (daily production of doughs) and level of inhalable and thoracic dust (figure 1), as well as associations between inhalable and thoracic dust across task groups and type of bakeries (table IV and figure 2), were described by Pearson’s correlation coefficient (r) again using the log-transformed data.

Tests were considered significant at a p-value of ≤ 0.05 . The data were analyzed using the software package IBM SPSS version 22.0 for Windows (IBM SPSS Inc., Chicago, IL, USA). The mixed effect models were analyzed using STATA version 13.1 (StataCorp LP, Texas, USA).

RESULTS

Exposure to flour dust and production-related determinants of exposure

Sixty-eight bakers participated in the exposure assessment, comprising a total of 107 inhalable and 61 thoracic personal dust samples. The mean duration of sampling time for inhalable dust was 398 minutes (range 154 – 568, standard deviation (SD) 81) in 2012 (n=60), and 426 minutes (range 255 - 555, SD 65) in 2009-2010 (n=47). The mean duration of sampling time for thoracic dust (n=61) was 403 minutes (range 154 – 568, SD 80). A total of 18 (30%) and 17 (28%) of the measurements of inhalable and thoracic dust, respectively, had a sampling time less than 360 minutes. Main reasons for shorter sampling times were medical examinations related to the ongoing epidemiological study, or transfer of the bakers from dough-handling tasks to other tasks not representative of being a baker (e.g. wrapping and administration). Hence, the measurements were regarded as representative of the full shift exposure, and the measured levels were used without further adjustment for unsampled time.

Inhalable dust

Repeated measurements of inhalable dust were obtained for the majority of the bakers (34 of 47 bakers, 72%) with a mean of 2.3 measurements per worker (range 1-8). Bakers overall (n=107) geometric mean personal exposure was 2.6 mg/m³ (95% CI: 2.0, 3.2) (table II). Twenty

nine percent of the measurements were above the Norwegian OEL of 3 mg/m³, while only 15% were below 1 mg/m³. None of the measurements was below the level of detection.

The exposure levels measured in 2009/2010 (n=47) were significantly lower ($p<0.001$) than the exposure levels measured in the same four bakeries in 2012 (n=22), the geometric mean exposure level increasing from 1.3 mg/m³ (95% CI: 1.0, 1.6) in 2009/2010 to 2.7 mg/m³ (95% CI: 2.1, 3.3) in 2012. The difference was mainly ascribed to a marked increase in exposure in the two large industry bakeries (C and D, data not shown).

For the inhalable dust measured in 2012 the between-worker ($_{BW}S^2$) variance (0.31, SD 0.11) was markedly larger than the within-worker ($_{WW}S^2$) variance (0.14, SD 0.04) in the model before any fixed effects were included (null-model) (table III). There was little variation in these variance components when including each of the determinants (variance component ratio ($_{WW}S^2/_{BW}S^2$) ranging from 0.45 to 0.56, except for “tasks” ($_{BW}S^2 = 0.19$, $_{WW}S^2 = 0.13$, $_{WW}S^2/_{BW}S^2 = 0.68$).

The exposure to inhalable dust differed non-significantly by a factor of two across the bakeries with geometric means ranging from 1.3 to 2.6 mg/m³ (table II), bakeries explaining 11% of the total variation (table III). Again, except from “tasks”, these variance estimates showed only minor changes when fixed effects were included (table III). Also for the determinant “tasks” there was little variation except for a low level for the five measurements taken during baking of goods, an obviously low exposure task where the baker is not handling the flour (table II). When excluding this task we did not find any difference in exposure to inhalable dust between the other tasks (data not shown). Further, none of the other assessed determinants could significantly explain the variation in exposure to inhalable dust. No major

changes in the results were found when repeating the analysis including the measurements collected in 2009/2010 in four of the bakeries. However, “tasks” explained 0.31% of the total variation ($p > 0.001$) with $w_w S^2 / b_w S^2$ -ratio approaching one ($b_w S^2 = 0.22$ (SD 0.08) and $w_w S^2 = 0.21$ (SD 0.04)).

Thoracic dust

Repeated measurements of the thoracic aerosol fraction were also obtained for the majority of the bakers (20 of 29 bakers, 69%) with a mean of 2.1 measurements per worker (range 1-6). Bakers’ overall ($n=61$) geometric mean exposure to the thoracic aerosol fraction was 0.33 mg/m^3 (95% CI: 0.3, 0.4) (table II). No measurement was below the level of detection.

As for the inhalable dust, the between-worker variance ($b_w S^2$ 0.34, SD 0.12) was larger than the within-worker variance ($w_w S^2$ 0.13, SD 0.03) when including all measurements of thoracic dust before including any fixed effects. Again, only minor changes in these variance estimates were seen when fixed effects were included. In contrast to inhalable dust, the exposure to the thoracic sub-fraction increased significantly with increasing daily production volume in mixed models ($R^2=0.18$) and also without adjustment for repeated measurements ($r=0.38$, $p=0.02$) (figure 1). The exposure level also differed significantly according to the presence of a confectionary unit in the same premises ($R^2=0.21$), the bakeries having the confectionary unit in a separate room having a higher exposure level than having it in close proximity or none at all. We found no statistically significant difference in exposure to the thoracic aerosol fraction across task groups, when excluding the single observation of “*baking of goods*” (table III). Although not statistically significant the exposure also varied across bakeries ($R^2=0.27$), type of bakery ($R^2=0.16$), and “number of silos” ($R^2=0.20$). These explanatory variables were strongly

correlated due to a structural dependency caused by the variables having similar values within each bakery. We nevertheless ran a forward stepwise multivariate model, resulting in no other variables being significant after daily production volume had been included (data not shown).

Extrathoracic dust

By subtracting the measured values of the thoracic dust from the measured values of inhalable dust (2012) we estimated the exposure to extrathoracic dust. The overall (n=58) geometric mean was 2.2 mg/m³ (95% CI: 1.9, 2.7, range 0.2 – 9.4 mg/m³).

Correlations between the various aerosol fractions

Overall, thoracic dust represented 15% of the inhalable dust, the fraction being rather stable across the other examined determinants (table II). The overall correlation between inhalable and thoracic dust on log-scale was nevertheless moderate ($r=0.52$, $p<0.001$), with the highest estimate for craft bakers (table IV and figure 2). The inhalable dust correlated significantly with the thoracic sub-fraction during dough making ($r=0.43$) and when the baker performed all the baking-related tasks (craft baker) ($r=0.62$), but not during dough forming ($r=0.01$). However, these differences were not statistically significant when evaluated by introducing an interaction term between task group and inhalable dust in the regression model with thoracic dust as the dependent variable. When grouping the data according to the type of bakery, the correlation between the inhalable dust and thoracic aerosol fractions were moderate for all bakery types ranging from 0.45 to 0.62. Due to the high fraction of extrathoracic dust and the mutual relationship between the two in the present study, the overall correlation between inhalable dust and estimated extrathoracic dust was very high ($r=0.97$, $p<0.001$), ranging between 0.95-0.99 ($p>0.001$) within the various task groups.

DISCUSSION

We found that the bakers included in the present study had a geometric mean exposure of 2.6 mg/m³ inhalable dust, with the mean ranging between 1.3 and 2.6 mg/m³ across the individual bakeries. Twenty-nine percent of the measurements were above the Norwegian OEL of 3 mg/m³. The exposure variability for inhalable dust was not statistically significantly explained by any of the examined production-related determinants. For the thoracic aerosol fraction, several determinants could explain part of the variance including bakery, bakery type, production volume, number of silos, and having a confectionary unit in the same premises as the bakery, each explaining between 16 and 27% of the total variation in a random effect model when included as single factors into the model. However, the high correlation between these explanatory variables in the study prevented a rigorous estimation of the relative importance of the examined determinants.

The bakers' exposure to inhalable flour dust in the present study is comparable to the exposure levels reported from other published exposure assessments using the same sampling methodology (PAS6) during the past 15 years, ranging from a mean geometric exposure level of 1.0 to 4.5 mg/m³ (14-18). Results from two dose-response studies with detailed exposure assessments indicate that exposure levels ≥ 1 mg/m³ inhalable flour dust increase the risk for sensitization (6) and rhinitis (19), while the threshold for asthma is reported to be at or above 3 mg/m³ inhalable dust (19). Although the descriptive overall percentage of measurements exceeding the OEL in our study (29%) is a rather unprecise estimate of individual cumulative health risk, the results indicate that Norwegian bakers' present exposure to flour dust most likely represents a risk for respiratory diseases. These relatively high exposure levels were found

although the knowledge about flour dust's harmful effects on the respiratory system is well recognized, and in spite of a sustained focus on reducing the exposure levels from regulatory bodies and the trade itself.

Extrathoracic dust, thus particles depositing in the upper airways, contributed with approximately 85% of the inhalable dust, i.e. overall exposure level averaging 2.2 mg/m³. Coarse dust particles tend to sediment close to the dust source, i.e. dough mixer. Hence, it is likely that the extrathoracic dust concentration will decrease downstream of the dough mixer, and that the fraction of thoracic dust will increase. In the present study, we could not find any statistically significant differences in the fraction of thoracic dust in inhalable dust across the production process (tasks) and bakery types. This contrasts a previous study reporting that only 9% of the airborne particles mass in dough making area had a mean particle diameter $\leq 6 \mu\text{m}$, while the corresponding percentage in the area for roll production was as high as 52% (20). In a study of dustiness at a pasta production factory the thoracic fraction of inhalable dust was reported to be lowest for the packers (28%) and kneader of dough (30%) on the manual line, and highest among operators on the automatic lines (47%) (21). No information on local exhaust systems was given.

The overall correlation coefficient between inhalable and thoracic dust on the log scale was moderate ($r=0.56$). This correlation was highest for the bakers performing all the baking-related tasks and non-existent for dough making, although this difference was not significant due to small numbers. Still, this variation underlines the need of more knowledge about how these aerosol fractions are distributed across the production process, bakery types and probably product types before correction factors for the various aerosol fractions can be used in translating available measurements of inhalable dust into thoracic or extrathoracic dust.

The specific job of a bakery worker has been identified as the most important source of variability for both inhalable dust (14,17,22) and total dust (23,24), and it has been suggested that a categorization of bakers into exposure groups based on their specific jobs or task will lead to sufficient contrast in average exposure levels when examining flour-induced respiratory effects. In the present study, bakery type was not a major explanatory factor for any of the two aerosol fractions examined. Further, except from the low exposure during the task “baking of goods”, we did not find significant differences across the task groups that involved handling of dough (mixing of dough, forming of dough, and the combination of all baker-related tasks). As reported in most studies assessing variability in flour dust exposure (14,17,24,25), the total between-worker variance were higher than the within-worker variance for both inhalable and thoracic dust. Except for the tasks performed, both the between- and within-worker variance components, as well as the variance component ratios ($_{WW}S^2/_{BW}S^2$), were rather stable for both dust fractions also when fixed effects were included. This indicates that differences in exposure between workers were larger than between work shifts on consecutive days. Also, since we for some of the bakeries only had one or two bakers available for sampling (craft bakeries), this between worker variance probably reflects difference in exposure between the bakeries rather than behavioral factors between workers.

However, the overall between- and within-worker variance being 0.31 and 0.14, respectively, in the present study was lower than reported in these other studies. The lower overall variability was also reflected in rather low GSDs of 2.1 and 1.9 for inhalable and thoracic dust, respectively, in the present study compared to GSDs ranging from 2.5 to 5.1 in other studies (14,17,22-24). . The relatively low variability in our measurements probably hampered the possibility to find

significant determinants of exposure. One reason for the more homogenous exposure in the present study population, which we assume to be representative for the Norwegian baker industry, is that it in contrast to the above mentioned studies only included bakers involved in dough-handling processes, and not wrappers, confectioners, and personnel involved in expedition and administration. Also, although a baker has mixing of dough as the principal work task, they will also contribute on the production line depending on where needed, giving the possibility of a misclassification of the exposure groups and a more homogeneous exposure in our study than would have been the case if the bakers only performed one of the dough-handling tasks during one sampling day. In the present study we did not have an estimate of time spent per task which could have been used in assessing the impact of the different tasks on bakers overall exposure to flour dust. However, the misclassification error introduced by dichotomizing presence of task is likely to be lower than the measurement error bias introduced by estimating the duration of a task (26).

Previous studies have reported that use of a closed silo system, thus decreasing the number of flour bags handled in the dough mixing area and enabling a closed transmission of flour to the mixer tub, largely decreases exposure to flour dust (17). The same study also reported that using a vacuum cleaner instead of a broom decreased the exposure. Refitting of the mixer lid to prevent spillage, preferably in combination with dust control training, has also been found to reduce bakers' inhalable dust exposure (27). We could not find any effect of such control measures in our survey. The reason for this could be that the control measures observed in the present study might not function efficiently enough to have significant impact on the exposure levels. Thus, some measures were only "partially" introduced (i.e. presence of local exhaust

system in mixer, lid on mixer), or was not functioning satisfactorily in any of the included bakeries (i.e. mechanical ventilation system, industrial vacuum cleaner) (table I).

The exposure level measured in the two sampling rounds differed statistically significantly from each other, mainly caused by a marked increase in two of the four bakeries sampled twice over the period of 2-3 years. We do not have information about the production, implemented control measures or other factors for the measurements performed in 2009/2010 that could explain this increase. Nevertheless, fluctuations in exposure level due to production-related factors, and hence variation in exposure levels over time, is probably representative for this industry and should be taken into account when assessing bakers' cumulative exposure to flour dust.

A shortcoming in the present study is the lack of information on specific allergens. Previous studies indicate that measurement of exposure of flour dust is not sufficient as surrogate exposure measure of the allergens found in flour dust. While Burstyn and coworkers (28) reported that the types of products and type of flour used in a bakery explained 49% of the variability in the wheat antigen content of inhalable flour dust, Niewenhuijsen and coworkers (23,29) found that although the overall correlation between average exposure levels of inhalable dust and wheat allergen was high ($r=0.86$, p-value not given) (1995b) this relationship and the airborne flour protein concentrations varied between different areas in a bakery (1994). Houba and coworkers (14,30) also reported that the content of wheat allergen and alfa-amylase varied among bakery types and job titles (14). Hence, the lack of consistent reports of a strong correlation between flour dust and specific allergens found in flour dust, as well as knowledge about how allergens are distributed in respect to type of flour, production type and task, limits

the usefulness of exposure measures based on gravimetric analysis of flour dust only when assessing dose-response relationship between flour dust and flour-induced sensitization and airway diseases.

CONCLUSION

Norwegian bakers are still exposed to flour dust at a level that is likely to increase their risk of sensitization and development of rhinitis and asthma. Extrathoracic dust – likely the most relevant sub-fraction in respect to flour-induced sensitization in the upper airways – represented the main proportion of the measured inhalable dust.

RECOMMENDATIONS

A decrease of present exposure levels in bakeries is imperative to protect bakers from the development of chronic diseases of the respiratory system. Previous studies have reported that use of a closed silo system, using a vacuum cleaner instead of a broom, refitting of the mixer lid to prevent spillage in combination with dust control training is efficient in order to reduce bakers' dust exposure. It is imperative to ensure that control measures already implemented in the bakeries are used correctly.

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TABLE I. Characteristics of the included bakeries during the sampling period.

Bakery	A	B	C	D	E	F	G
Bakery type	Craft bakery	Craft bakery	Industry bakery	Industry bakery	Industry bakery	Industry bakery	Soft flatbread bakery
Number of bakers	5	One in every workshop	4	6	3	5	4
Level of automatization	Low	Low	High	High	High	High	High
Confectionary in the premises	Yes, in an adjacent room	No	Yes, in a separate room	No	Yes, in an adjacent room	Yes, in a separate room	No
Production volume							
- daily number of doughs	20	8-10 at every workshop	80-100	50-70	60-80	100	17
- daily number of breads	300	370	30 000	NA	3 600	20 000	NA
Wheat flour (% of total)	85	80	70	70	60-70	70	100
Mechanical ventilation	Deficient, lack of maintenance	Lacking, turned off or blocked	Not satisfactory*	Lacking	Lacking	Not satisfactory, undersized	Lacking
Number of silos for flour	None	None	5	4	5	5	1
Smaller silos for flour and other components in small bags	No	No	No	No	Yes	No**	No
Lid on mixers	On half of the mixers	One of three	Yes	Yes	On most of the	Yes	Yes

		workshops			mixers		
Local exhaust system on mixer	No	No	Yes	No	Partly	No	Yes
Use of pressurized air pistol for daily cleaning	Never	Never	Daily	Daily	Sometimes	Daily	Daily
Use of industrial vacuum cleaner for daily cleaning	No	No	Yes	No	No	No	No

*Problems with the input air

**The bakery had an installed system, but it was not operational during the sampling period

NA – not available

TABLE II. Bakers' exposure to inhalable and thoracic dust (mg/m^3) in seven Norwegian bakeries (2009-2012).

Variable	Group	Inhalable dust					Thoracic dust					
		N	G M *	G S D	95% CI	Min - max	N	% of in h. du st	G M *	G S D	95% CI	Min - max
All bakers	2009-2012	107	2.55	2.1	2.0, 3.2	0.26 – 9.93	61	14.7	0.33	1.9	0.3, 0.4	0.06 – 1.13
Bakery	A	14	2.23	1.6	1.2, 4.2	0.87 – 3.10	8	14.6	0.35	1.2	0.2, 0.6	0.25 – 0.46
	B	9	2.32	2.0	1.3, 4.2	0.78 – 4.51	10	15.7	0.28	2.2	0.2, 0.4	0.07 – 1.09
	C	11	2.61	2.1	1.6, 4.3	0.93 – 9.93	2	18.0	0.79	1.6	0.4, 1.8	0.56 – 1.13
	D	20	1.30	2.8	0.8, 2.0	0.26 – 6.18	7	8.8	0.29	1.6	0.2, 0.5	0.13 – 0.52
	E	24	1.43	1.8	0.9, 2.3	0.48 – 5.24	4	19.2	0.31	1.4	0.1, 0.7	0.19 – 0.40
	F	15	2.59	2.2	1.6, 4.1	0.28 – 6.18	15	19.9	0.43	2.1	0.3, 0.6	0.06 – 1.05
	G	14	2.51	1.5	1.5, 4.2	1.29 – 4.79	15	9.5	0.21	1.5	0.1, 0.3	0.07 – 0.42
Bakery type	Industry bakery	70	1.83	2.3	1.4, 2.3	0.26 – 9.93	28	16.9	0.41	1.9	0.3, 0.5	0.06-1.13
	Craft bakery	23	2.29	1.7	1.4, 3.6	0.78 – 4.51	18	15.2	0.30	1.8	0.2, 0.4	0.07 – 1.09
	Soft bread bakery	14	2.52	1.5	1.5, 4.3	1.29 – 4.79	15	9.5	0.21	1.5	0.1, 0.3	0.07 – 0.42
Task	Dough	5	2.	2.	1.8,	0.33 –	3	13	0.	2.	0.2,	0.07 –

	making	8	19	0	2.7	9.93	3	.7	32	0	0.4	1.13
	Dough forming	2 1	2. 32	2. 0	1.7, 3.2	0.41 – 5.24	1 0	16 .5	0. 47	1. 5	0.3, 0.7	0.19 – 0.68
	Craft baker (all tasks)	2 3	2. 27	1. 7	1.6, 3.3	0.78 – 4.51	1 7	15 .2	0. 32	1. 9	0.2, 0.5	0.07 – 1.09
	Baking of goods	5	0. 36	1. 6	0.2, 0.7	0.26 – 0.66	1	–	0. 06	–	0.02, 0.2	–

N = number of measurements

GM = geometric mean

GSD = geometric standard deviation

CI = confidence interval

*adjusted for repeated measurements using mixed models.

TABLE III. Explained variance (R^2) of exposure to inhalable and thoracic dust in seven bakeries (2012) using linear mixed effects models adjusting for repeated individual measurements (random effects) and including each of the determinants as fixed effects at a time (significant associations in bold font).

Variable	Group	Inhalable dust (n=60)				Thoracic dust (n=61)			
		p-value	R^2	$BW S^2$ (SD)	$WW S^2$ (SD)	p-value	R^2	$BW S^2$ (SD)	$WW S^2$ (SD)
Null model				0.31 (0.11)	0.14 (0.04)			0.34 (0.12)	0.13 (0.03)
Bakery	Seven bakeries	0.576	0.11	0.26 (0.10)	0.14 (0.04)	0.067	0.27	0.21 (0.09)	0.14 (0.04)
Bakery type	Industry bakery/ craft bakery/soft bread bakery	0.931	0.008	0.30 (0.11)	0.14 (0.04)	0.059	0.16	0.26 (0.10)	0.14 (0.04)
Task	Dough making / dough forming / craft baker (all tasks) / baking of goods	0.003	0.59	0.19 (0.08)	0.13 (0.03)	0.163	0.018	0.28 (0.10)	0.12 (0.03)
Work shift	Day / Afternoon/Evening / Night	0.29	0.08	0.27 (0.11)	0.15 (0.04)	0.85	0.04	0.34 (0.12)	0.13 (0.03)
Season	Spring / Summer / Autumn / Winter	0.62	0.02	0.30 (0.11)	0.14 (0.04)	0.71	0.04	0.32 (0.12)	0.13 (0.04)
Confectionary unit in the same premises	No / Yes (separate room) / Yes (same/proximate room)	0.59	0.03	0.29 (0.11)	0.14 (0.04)	0.019	0.21	0.24 (0.10)	0.14 (0.04)
Daily	< 20 / 21 – 70 /	0.59	0.03	0.29	0.14	0.03	0.1	0.25	0.14

production volume (number of doughs)	> 70			(0.11)	(0.04)	3	8	(0.10)	(0.04)
Silos for limiting the use of bagged flour products	0 / 1*/ 4 / 5	0.97	0.01	0.30 (0.11)	0.14 (0.04)	0.05 5	0.2 0	0.24 (0.10)	0.14 (0.04)
Lid on mixer	Yes / Partly / No	0.64	0.03	0.29 (0.11)	0.14 (0.04)	0.68	0.0 2	0.33 (0.11)	0.13 (0.03)
Mechanical ventilation	None / Insufficient	0.55	0.01	0.30 (0.11)	0.14 (0.04)	0.13	0.0 8	0.30 (0.11)	0.13 (0.04)
Local exhaust system in mixer	Yes / Partly / No	0.48	0.03	0.30 (0.11)	0.14 (0.04)	0.78	0.0 2	0.33 (0.12)	0.13 (0.03)
Use of pressurized air for cleaning	Never / If necessary / Daily	0.58	0.03	0.29 (0.11)	0.14 (0.04)	0.89	0.0 05	0.34 (0.12)	0.13 (0.03)

R²= explained variance

* = soft bread bakery.

TABLE IV. Associations (Pearson correlation coefficients, r) with the corresponding 95% confidence interval (95% CI) between the inhalable and thoracic dust among bakers (2012, $n=58$) across bakery type and task groups.

Model	N	Pearson correlation coefficients	
		r (95% CI)	p -value
All samples	58	0.52 (0.30, 0.69)	<0.001
Bakery type			
<i>Craft bakeries</i>	17	0.62 (0.20, 0.85)	0.008
<i>Industry bakeries</i>	28	0.45 (0.09, 0.70)	0.016
<i>Soft flatbread bakery</i>	13	0.54 (-0.02, 0.89)	0.06
Task group			
<i>Dough making</i>	30	0.43 (0.08, 0.68)	0.019
<i>Dough forming</i>	10	0.01 (-0.47, 0.49)	0.98
<i>Craft baker (all tasks)</i>	17	0.62 (0.20, 0.85)	0.008

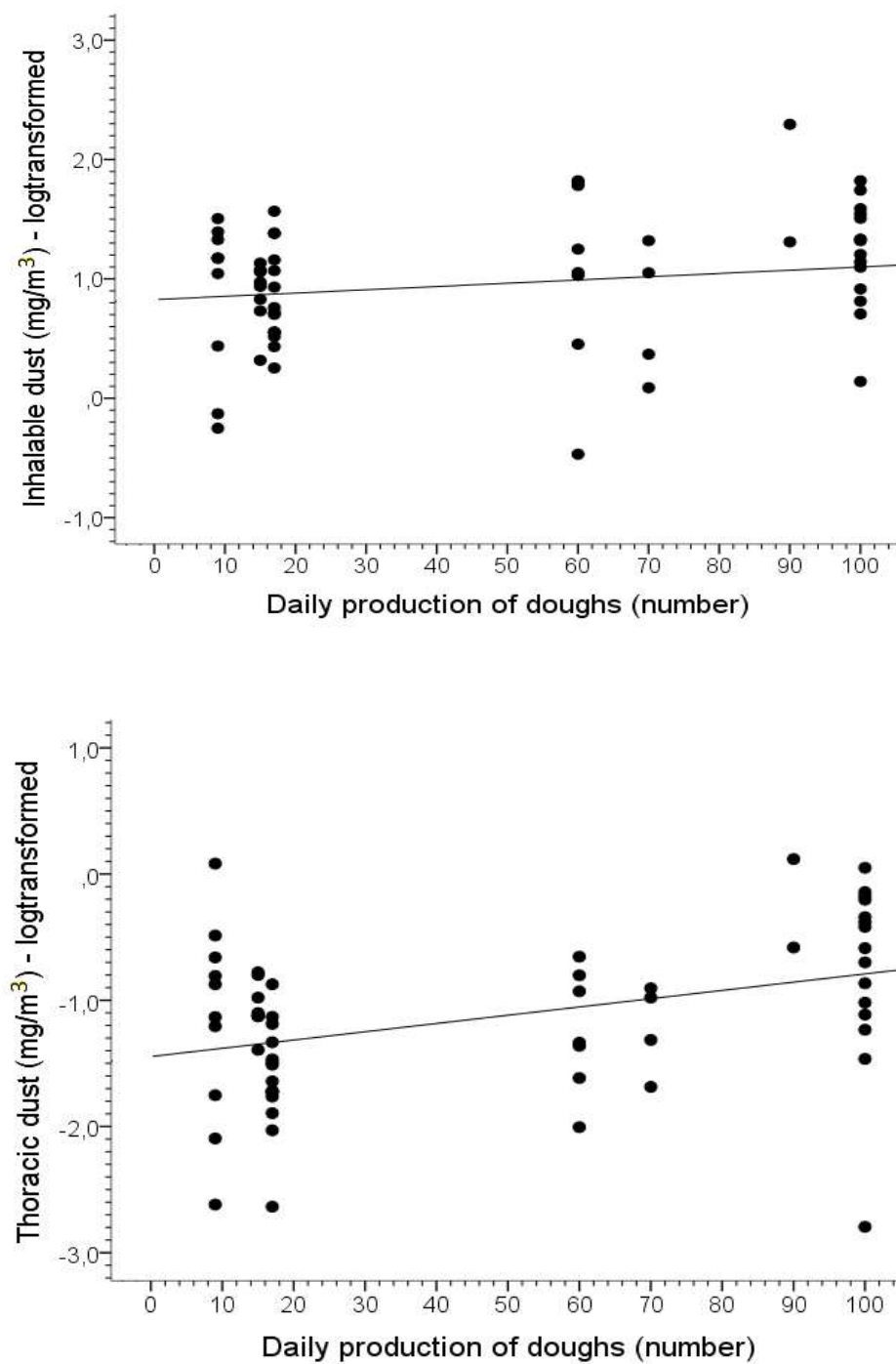
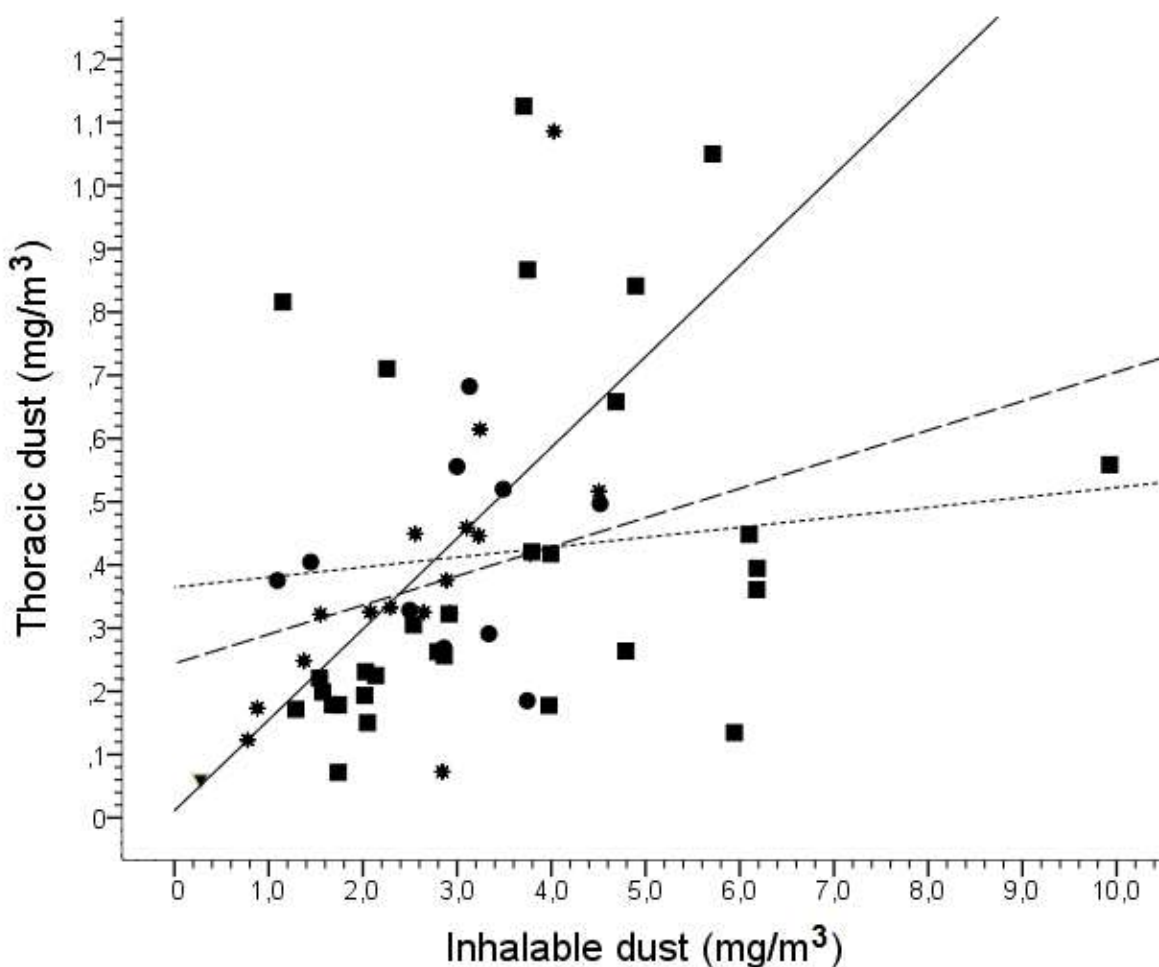


FIGURE 1. Association between daily production of doughs and concentration of inhalable ($r=0.17$, $p=0.21$) and thoracic dust ($r=0.38$, $p=0.02$).



- Dough making
- Dough forming
- *— All tasks (craft baker)
- ▼ Baking of goods

FIGURE 2. Association between the inhalable and thoracic dust among bakers (2012) across task groups. Both dust fractions have only been measured once for the task “baking of goods”, resulting in one point only.