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Modelling Exposure in Flour Processing Sectors in The Netherlands: a Baseline Measurement in the Context of an Intervention Program

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Introduction: Recent studies have shown that even low exposure levels to flour dust and related allergens can cause severe respiratory symptoms. In The Netherlands the Dutch government and responsible branch organizations [from bakeries (traditional & industrial), flour mills and bakery ingredient producers] signed a covenant to reduce exposure to flour dust and decrease the prevalence of work-related occupational airway disease. This paper describes a sector wide survey to measure exposure to flour dust, wheat allergens and fungal α-amylase. The results are being used to underpin various elements of the covenant.

Methods: A dataset containing 910 personal measurements was compiled from four field studies containing information on exposure and potential determinants. The dataset represents a baseline estimate of exposure for four major flour processing sectors in The Netherlands. Exposure models for all sectors and agents were generated, based on job, tasks and company size, taking into account worker and company as random effect components. Use of control measures and, where possible, their effect were evaluated.

Results: Flour dust and enzyme exposures vary strongly between sectors. The job performed and specific tasks were identified as important determinants of exposure. The number of identified control measures during walk-through surveys, and their effectiveness in reduction of dust exposure was generally limited. The exposure models explained significant exposure variability between companies and workers but performed poorly in explaining day to day differences in exposure.

Discussion: The dataset serves as a baseline estimate and will be compared with a post intervention survey in the near future. The information obtained on control measures can be used to optimize the intervention scenarios that will be implemented in the different sectors by external occupational hygienists. The predictive exposure models will provide a relevant measure of average personal exposure that will be used in the sector wide health surveillance system.

Keywords: bakeries; control measures; exposure modeling; flour dust; fungal α-amylase; wheat allergens

INTRODUCTION

Exposure to flour dust and related allergens is one of the most observed causes of occupational airway disease (OAD) and occupational asthma (OA) in Western Europe (Latza and Baur, 2005). Several studies show that prevalence of sensitization for wheat allergens and fungal α-amylase, and prevalence of OAD and OA, are high among workers exposed to flour dust (Brant *et al*., 2005; Brisman *et al*., 2000, 2004; Droste *et al*., 2003; Heederik and Houba, 2001; Houba *et al*., 1996a; Peretz *et al*., 2005).

In the Netherlands over 10 000 workers in bakeries, flour mills and baking ingredient producers (Heederik and Houba, 2001) are potentially exposed to high levels of flour dust (>>1 mg/m^3) and related allergens. From this group 28% is estimated to be sensitized against allergens present in the flour, compared to 2–4% in the general population.

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Prevalence of respiratory symptoms among workers exposed to flour can be as high as 60% of the population depending on the definition of the symptom and the (sub)population under investigation.

An analysis of epidemiological survey data (Heederik and Houba, 2001) showed no conclusive evidence for the existence of an exposure threshold for specific wheat sensitization. The epidemiological analysis indicated that even low inhalable flour dust levels (below 0.5 mg/m^3) might lead to sensitization of workers and cause OAD. Yet, the probability of sensitization and development of symptoms increases with increasing exposure (Heederik and Houba, 2001; Cullinan *et al*., 2001; Brisman *et al*., 2000; Houba *et al*., 1998, 1996a).

Previous studies confirm that exposure to both flour dust and allergens can be high (>>1 mg/m^3 for flour dust, >>10 μg/m^3 for wheat allergens and >>10 ng/m^3 for fungal α-amylase) (Pater *et al*., 2003; Bulat *et al*., 2004; Elms *et al*., 2006, 2005; Nieuwenhuijsen *et al*., 1999). Since recent studies show that time trends do not indicate a decrease in exposure (Creely *et al*., 2006; Pater *et al*., 2003), more rigorous interventions in baking and flour processing sectors are needed. In the Netherlands the Ministry of Social Affairs and Employment signed a covenant with branch organizations representing the baking industry (traditional and industrial), flour mills and baking ingredient producers with the main goal to reduce exposure to flour dust and decrease the prevalence of work-related OAD. Key elements of this covenant are: inform workers about hazards, reduce exposure by implementation of a sector wide intervention program and the installation of a health surveillance system (HSS) with the aim to detect allergic diseases in an early stage by using a formalized questionnaire approach. The underlying rationale of the questionnaire approach to determine individual probabilities of becoming sensitized have been described elsewhere (Suarthana *et al*., 2005).

The overall aim of this paper was to use available exposure measurements from several recently performed exposure surveys to create an extensive exposure database with information on personal exposure to flour dust, wheat allergen and fungal α-amylase in the four main flour processing industries in the Netherlands. This database serves as a baseline population exposure estimate in the occupational hygiene intervention program and will be used to evaluate its effectiveness. Furthermore, this database can be used to develop exposure models based on jobs and tasks performed to enable the generation of individual exposure estimates within the HSS. The database will also be used to obtain insight into the presence and use of control measures in the different sectors and where possible evaluate their effectiveness.

METHODS

Population

The database described in this paper consists of measurement data from four exposure surveys performed between 2000 and 2005. The largest survey was carried out in 2000/2001 in four major flour processing sectors in the Netherlands: bakeries (traditional and industrial), flour mills and bakery ingredient producers. This exposure study was performed as part of a large epidemiological study that investigated the respiratory effects related to occupational exposure to flour dust and related allergens among workers in the four sectors. The main aim of the exposure study was to obtain a detailed overview of personal exposure levels across all jobs performed. In addition, the study was set up to explore the current use of control measures. For the epidemiological study a random selection of companies from all four sectors was approached to participate. When agreeing to participate a random selection of workers from each company was asked to fill in an epidemiological questionnaire. In total 692 workers returned a questionnaire. Of these workers ~70% also agreed to participate in the exposure assessment survey. To increase the number of exposure measurements, all other workers in the visited companies were also approached to participate in the exposure survey. Eventually, 551 workers in 84 companies were sampled between 1–3 times, resulting in 638 personal exposure measurements.

In addition, three smaller surveys investigating exposure levels in one or several companies were added to the database. The majority of workers in these companies were included in the surveys. The studies were performed in 2005 and contained 47 (flour mill), 39 (traditional bakeries) and 186 (industrial bakeries) personal exposure measurements, respectively.

Companies and workers involved are a representative cross-section of the total working population in the four sectors, including all relevant jobs and activities performed in the four sectors. In total 910 personal exposure samples were included in the database. Repeated samples were available from ~23% of the population (170 workers). Table 1 gives a description of the four sectors and the different jobs per sector.

Personal exposure measurements and walk-through survey

Personal air samples were obtained from a random sample of workers from companies in each sector. The number of observations per individual ranged from 1 to 3. The dust samples were collected using a portable pump (Gillian GilAir5) with a flow rate of 2 l/min and a Teflon filter (Millipore, PTFE, pore size

Table 1. Description of sectors and jobs within sectors with their main activities

Sector with related jobs	Job description with most important tasks
Traditional bakeries	Also known as craft bakeries, generally low grade of automation, large variety of bread and confectionary products (>>100) in low quantities.
Bread baker	Bread production process, weighing ingredients, dumping ingredients (bagged or from silo) operating mixers (preparing dough), processing dough, operating ovens. Often also cleaning and wrapping activities.
Confectioner	Pastry production process, weighing ingredients, preparing dough, using sheeter, large part of the work is generally finishing of pastry and cakes (decorating).
General baker	Combination of tasks from the two above.
Industrial bakeries	Bakeries with a high grade of automation often specialized in specific products (bread or pastry). Nevertheless still has many activities with flour and/or dough products.
Bread baker	Works along the bread production lines, dough making, operating machinery (dough line) processing dough, control of process, troubleshooting.
Confectioner	Works along the pastry production line, majority of work is finishing/decorating pastry. Also production of cookies and cakes. Control of processes
Dough maker	Makes batches of dough, weighing ingredients, operates mixers, dumping of ingredients, sometimes small cleaning activities, troubleshooting.
Cleaner	All cleaning activities, vacuuming, sweeping, mopping, cleaning with pressures air.
Maintenance worker	Periodical maintenance of machinery, incidental repair of machinery when malfunctioning.
'Low exposed job'	Group of jobs not directly involved in production process (flour handling) or performing substantial cleaning or maintenance work like, oven operators, wrappers, administrative personal, etc.
Flour mills	Involved in milling grains, corn, soy, etc. Also increasingly producing pre-mixes (with all kind of additives) directly for the baking industry. Some have very specialized additional processes (e.g. producing food fibres).
Quality controller	Primarily involved in checking the quality of both ingredients and end products. Taking samples throughout the production process, lab analysis, test baking, small cleaning activities.
Cleaner	All cleaning activities, vacuuming, sweeping, mopping, cleaning with pressures air.
Foreman/boss	Generally leads a team of workers often takes part in (some of) the regular activities but also responsible for planning and administrative activities.
Mill operator	Operates the mills, large part of the work takes place from an (enclosed) operating room. But also often hands on activities on the workfloor around the mills. Small cleaning activities, small maintenance, trouble shooting.
Operator bagging	Operates the bagging lines, can be control work or hands on filling of bags. Also palletizing bags, closing bags (sewing).
Storage worker	Works in ingredient or end product storage. Weighing of ingredients, supplying of several departments, small cleaning work, palletizing of products, administrative work.
General operator	Primarily working in general operating rooms overlooking (several) processes. Administrative work. Occasionally assistance on work floor in any of the processes.
Maintenance workers	Periodical maintenance of machinery, incidental repair of machinery when malfunctioning.
Loader/unloader	Loading and unloading of trucks/ships, driving fork lift trucks (occasionally), operating silo's, unloading grain ships, operating crane.
Chauffeur	Driving of trucks, driving of fork lift trucks (major part of the work day).
Silo builder	Technical worker specialized in building and maintenance of storage silo's.
Ingredient producers	Producing ingredients for baking industry, primarily pre-mixes based on flour or other bulk and specialized additive mixtures for bread or pastry. Also other additives grease, pastes, sugar mixtures, fruit mixtures etc.
Quality controller	Primarily involved in checking the quality of both ingredients and end products. Taking samples throughout the production process, lab analysis, test baking, small cleaning activities.
Production worker	Gives assistance throughout the production processes, often a lot of conveyer belt work. Majority of work in grease/paste department but also occasionally other departments.
Foreman/boss	Generally leads a team of workers often takes part in (some of) the regular activities but also responsible for planning and administrative activities.
Operator bagging	Operates the bagging lines, can be control work or hands on filling of bags. Also palletizing bags, closing bags (sewing).
Storage worker	Works in ingredient or end product storage. Weighing of ingredients, supplying of several departments, small cleaning work, palletizing of products, administrative work.
Maintenance worker	Periodical maintenance of machinery, incidental repair of machinery when malfunctioning.
Weigher	Weighs and mixes ingredients (additives) that are send to different departments to be mixed to batch flour or other bulk products.

Table 1. *Continued*

Sector with related jobs	Job description with most important tasks
Dumper (ingredients)	Empties bulk products (from silo or big bags) and bags of additives in large mixers.
General operator	Primarily working in general operating rooms overlooking (several) processes. Administrative work. Occasionally assistance on work floor in any of the processes.
Loader/unloader	Loading and unloading of trucks/ships, driving fork lift trucks (occasionally), operating silo's, operating crane.

1.0 micron) mounted in a PAS6 sampling head. Sampling was performed in the breathing zone of the worker for 4–10 h (full shift). Dust levels were determined by weighing (analytical balance: Mettler AX 105 DR) the filters in a climate-controlled weighing room where the filters were conditioned for 24 h prior to weighing (40% humidity, 22°C and 1020 Pa air pressure). The limit of detection (LOD) was assessed as the average weight difference of the blank filters plus three times the standard deviation, amounting to 0.17 mg dust on the filter. A few samples had values below the analytical LOD. These samples were assigned with a value two-thirds of the LOD prior to statistical analysis. The concentration of wheat allergens and fungal α-amylase were determined in the majority of samples using specific immunochemical analysis (specific EIA). In these analyses proteins were extracted from the dust on the filters through a variety of extraction and elution steps. Subsequently, extraction fluid was analyzed using specific enzyme immuno assay (EIA) as described in detail by Bogdanovic *et al*. (2006a, b). The same assay was used for analysis of allergens in all four surveys.

A walk-through survey was carried out in all companies, using a standardized checklist to register relevant exposure determinants (job and tasks performed, specific control measures). Workers were followed throughout their shift and information on tasks performed and specific work characteristics was registered. The information was obtained independently for each measurement day. For three tasks (weighing ingredients, processing dough (sprinkling flour) and cleaning) process characteristics were identified that could influence exposure. For processing of dough these were: use of stainless steel tables, use of oil and dust-free flour. During the weighing of ingredients, the use of a silo with closed mixing tub and the absence of bagged ingredients were evaluated as control measures. For cleaning, the effect of the use of a vacuum cleaner instead of brooms or pressured air was evaluated. Finally, we evaluated the effect of local exhaust ventilation (LEV).

Exposure modelling

Descriptive statistics (histograms, normal probability plots) were applied to determine exposure distributions. Log transformed data were used for further analysis. Spearman correlation coefficients between exposure to flour dust and allergens were calculated using the PROC CORR procedure in SAS v8.2 (SAS Institute Inc.). The geometric mean and standard deviation were calculated, stratified by sector and job. Based on these results and observations in the field, some jobs in industrial bakeries were grouped because of comparable (low) exposure levels. This 'low exposed' job category consisted of: oven operators, wrappers, quality controllers, boss/foreman and storage workers. Bakery companies were also classed according to their size for both traditional and industrial bakeries.

Mixed effects models (PROC MIXED) were used to study associations between exposure to flour dust, wheat allergens, fungal α-amylase and covariates as well as random effects (Rappaport *et al*., 1999). Job, tasks and company size were considered as covariates. Random effect components considered were worker and company. Homogeneity of variance components between sectors was checked using log-likelihood ratio testing (Symanski *et al*., 2001; Van Tongeren *et al*., 2006; Weaver *et al*., 2001). For other determinants (e.g. jobs) the number of repeated measurements per strata was too small to perform a detailed analysis of homogeneity of variance components. A compound symmetric covariance structure was assumed.

Model building comprised of two steps. In the first step, univariate analyses were used to determine which variables were associated with exposure to flour dust, wheat allergens and/or fungal α-amylase. In the second step, stepwise model building was used starting with the variable which explained the most variance. Variables with a *P*-value of 0.1 or smaller were included. The increase in explained variance compared to the previous model was calculated as the difference in −2 log-likelihood. Statistical significance was established using the likelihood ratio test. If the model fit did not improve, expansion was stopped. Graphical analyses of residuals were performed to evaluate assumptions of homoscedasticity.

Control measures were evaluated after adjustment for job performed and related tasks. Measurements with missing data for a specific factor were left out of the analysis causing slight changes in the total number of measurements taken into account in the various analyses. Missing contextual data of measurements remained relatively small during analyses (generally <5% of measurements).

RESULTS

Exposure measurements

The final dataset comprised of 910 personal inhalable dust samples from 735 subjects and 99 companies. The database contained repeated measurements from 170 subjects. Table 2 reflects the average exposure levels for each sector (geometric means and standard deviations). Exposure to dust and wheat allergens is highest in flour mills, whereas workers in baking ingredient production plants are exposed to the highest levels of fungal α-amylase. For wheat allergens and fungal α-amylase in particular, a wide-range in exposure levels is often found within sectors and jobs, resulting in a large GSD. The overall correlation between exposure to flour dust and wheat allergens was 0.8 (range 0.71–0.83 for different sectors). The correlation between exposure to fungal α-amylase and flour dust was low, overall 0.4 (range 0.30–0.43 for different sectors).

Mixed effects models

Tables 3–6 shows the results from the mixed effects models with job, tasks and company size as covariates. Variance components with their respective confidence intervals and the total explained variance are given. The results of the different models are discussed below.

Traditional bakeries

Table 3 shows that exposure to all three agents was significantly higher for bread- and general bakers. Working in a large traditional bakery (>10 workers in production) was associated with a significantly higher exposure to flour dust and wheat allergens (approximately a factor 1.5). Dough making, sprinkling flour, weighing and cleaning increased exposure to one or more of the agents, while oven work and wrapping was associated with lower exposure to fungal α-amylase. Depending on the agent, models explained 15–50% of day to day variability and explained 10–35% of between company variability, respectively.

Industrial bakeries

Table 4 indicates that exposure differed with a factor 1.6 to 5 depending on the job performed and the agent of interest. Working in a large industrial bakery (>100 workers) is associated with a higher exposure to flour dust. Furthermore, tasks, such as dough making, sprinkling flour and processing dough are associated with higher exposure levels to one or more agents, while wrapping and cleaning are associated with lower exposure levels to wheat allergens and/or fungal α-amylase.

Between worker differences were for a large part (>60%) explained by our final models. On the other hand, day to day differences in exposure are poorly explained. For amylase almost 90% of total variability was associated with day to day differences in the final model.

Flour mills

Table 5 shows that exposures differed with a factor of 1.2–7 (flour dust), 2–35 (wheat allergens) and 3.5–24 (fungal α-amylase), respectively, compared to baseline exposure depending on the job performed. Workers who performed storage work, loading/unloading of goods, unloading grain and cleaning grain had a significantly lower exposure to flour dust and/or wheat allergens. Cleaning was associated with higher exposure levels for all three exposures, whereas mixing ingredients only increases the exposure to α-amylase.

Most of the variability in exposure to flour dust and wheat allergen was associated with differences between workers, of which the final models explained 50 and 30%, respectively. The remainder was day to day variability which was poorly explained by the final mixed effects models. For amylase all variability

Table 2. Mean exposure to total dust, wheat allergen and α-amylase in bakeries, flour mills and ingredient producers

Sector	*k*	*n*	*r*	*N*	Inhalable dust (mg/m^3)		*N*	Wheat allergens (μg/m^3)		N	α-Amylase (ng/m^3)	
					GM (GSD)[a]	Range		GM (GSD)	Range		GM (GSD)	Range
Traditional bakeries	65	174	26	200	1.5 (2.7)	0.2–318	171	7.4 (8.3)	0.1–5365	169	0.8 (6.5)	0.1–115
Industrial bakeries	20	303	75	381	1.0 (3.5)	0.2–292	346	3.6 (10)	0.1–7571	344	0.4 (6.0)	0.1–910
Flour mills	7	154	47	203	2.7 (4.5)	0.2–1837	185	10.4 (8.5)	0.1–3874	142	8.4 (9.7)	0.2–30 009
Ingredient producers	7	104	22	126	2.0 (5.8)	0.0–627	113	4.2 (12.1)	0.1–1517	113	33.5 (22.4)	0.2–889 054

k = Number of companies visited.
n = Number of subjects sampled.
r = Number of subjects with repeated measurements.
N = Total number of personal air samples taken.
[a]Geometric mean (geometric standard deviation).

Table 3. Estimates of model variables in final mixed effects model of the log transformed exposure to flour dust, wheat allergens and fungal α-amylase among traditional bakers

Model variables (fixed effects)		K[d]	Flour dust		Wheat allergen		α-amylase	
			β	*P*-value	β	*P*-value	β	*P*-value
Intercept[a]		—	−0.74	0.00	−1.05	0.01	−0.83	0.01
Jobs[b]	Bread baker	86	0.82	0.00	1.87	0.00	1.31	0.00
	General baker	65	0.46	0.01	1.00	0.01	1.37	0.00
Company size[c]	Large bakery	116	0.42	0.01	0.90	0.01	—	—
Tasks	Dough making	122	0.57	0.00	0.99	0.00	—	—
	Sprinkling Flour	93	0.31	0.03	0.85	0.00	—	—
	Weighing ingredients	112	–[e]	—	0.52	0.08	—	—
	Cleaning	93	—	—	0.48	0.06	0.54	0.03
	Oven work	96	—	—	—	—	−0.64	0.00
	Wrapping	65	—	—	—	—	−0.71	0.01
Var_b$_C$ (CI)[f]		—	0.19 (0.09–0.64)		1.08 (0.63–2.28)		1.61 (1.02–2.90)	
Var_b$_w$ (CI)[g]		—	[i]		[i]		[i]	
Var_w$_w$ (CI)[h]		—	0.67 (0.54–0.89)		1.67 (1.29–2.24)		1.43 (1.11–1.93)	
Total explained variability		—	27%		39%		9%	

[a]The intercept gives the exposure level working as a confectioner in a small bakery not performing any of the tasks in the model.
[b]Job confectioner is reference group.
[c]Small bakeries are reference group.
[d]Number of observations with factor present.
[e]Not in model, not significant at the α = 0.10 level.
[f]Variance component between companies (confidence interval).
[g]Variance component between workers (confidence interval).
[h]Variance component within workers (confidence interval).
[i]Random effect not significant in final model.

was assigned to differences between working days, of which ∼15% was explained by our model.

Baking ingredient producers

Table 6 indicates that exposure levels varied with a factor of 3–46 (flour dust), 1.3–40 (wheat allergens) and 2.7–200 (fungal α-amylase), respectively, depending on the job performed. Cleaning, weighing ingredients and bagging was associated with higher flour dust exposure. Packing pallets and weighing ingredients were associated with higher wheat allergen exposures. Paste/grease production significantly reduced exposure to wheat allergens and fungal α-amylase (with a factor 54 and 65, respectively).

Control measures

Potential control measures were not often observed and their actual use was generally limited. Some of the control measures were used but only to such a limited extent that it was not feasible to evaluate their effect. Some examples of control measures that were incidentally encountered were: use of liquid or paste bread improver (enzymes) instead of powder form, use of palletized additives instead of powder additives, use of closed bag compressors, elimination of use of pressured air, use of only wet cleaning methods instead of brushing and sweeping, extensive LEV throughout the factory. An extensive list of potential control measures in bakeries is described in the manual for dust control in bakeries (Goede *et al.*, 2004) [The reference of the dust control manual refers to the Dutch version. An English translation will shortly be available via the corresponding author.

Tables 7 and 8 give results of a small set of identified control measures that were evaluated quantitatively. Table 7 shows that control measures in bakeries were primarily identified during activities, such as the weighing of ingredients and processing of dough, and also for cleaning activities at industrial bakeries. The statistical analyses show that dumping of flour when weighing ingredients is associated with higher exposure. Use of a closed silo system largely eliminates this exposure. Use of dusting flour also leads to significantly higher exposure to flour dust. These eposures decreased when substitutes like oil, dust-free flour or a stainless steel worktable were used. For industrial bakeries the use of a vacuum cleaner (instead of a broom) reduced exposure. For the other sectors no data on specific control measures were obtained.

Table 8 indicates the results of LEV and its use. In <20% of the sampled bakeries proper LEV was present. In general, no significant effect on the average daily exposure to flour dust in bakeries was observed when LEV was installed. At flour mills LEV was present in ∼50% of the measured situations, especially at points where flour products were bagged

Table 4. Estimates of model variables in final mixed effects model of the log transformed exposure to flour dust, wheat allergens and fungal α-amylase among industrial bakers

Model variables (fixed effects)		K[d]	Flour dust		Wheat allergen		α-amylase	
			β	*P*-value	β	*P*-value	β	*P*-value
Intercept[a]			−1.08	0.00	−0.33	0.24	−1.14	0.00
Jobs[b]	Bread baker	87	1.19	0.00	1.60	0.00	1.07	0.00
	Confectioner	23	1.08	0.00	1.30	0.01	−0.67	0.10
	Dough maker	100	1.08	0.00	1.46	0.00	0.35	0.19
	Cleaner	12	0.53	0.09	0.06	0.93	−0.40	0.47
	Maintenance worker	21	1.05	0.00	1.18	0.01	0.41	0.28
Company size[c]	Large bakery	155	0.37	0.01	—	—	—	—
Tasks	Dough making	123	0.51	0.00	1.46	0.00	0.93	0.00
	Sprinkling flour	43	0.46	0.01	0.73	0.02	—	—
	Processing dough	147	—[e]	—	0.39	0.09	—	—
	Wrapping	68	—	—	−0.47	0.08	−0.79	0.00
	Cleaning	147	—	—	—	—	−0.48	0.01
Var_b_C (CI)[f]			[i]		0.37 (0.15–1.91)		0.27 (0.12–1.10)	
Var_b_w (CI)[g]			0.35 (0.16–0.54)		1.34 (0.71–1.97)		[i]	
Var_w_w (CI)[h]			0.70 (0.55–0.91)		1.73 (1.33–2.34)		2.22 (1.92–2.62)	
Total explained variability			36%		42%		9%	

[a]The intercept gives the exposure level working in a 'low exposed' job in a small bakery not performing any of the tasks in the model.
[b]'low exposed' job category is reference group.
[c]Small bakeries are reference group.
[d]Number of observations with factor present.
[e]Not in model, not significant at the α = 0.10 level.
[f]Variance component between companies (confidence interval).
[g]Variance component between workers (confidence interval).
[h]Variance component within workers (confidence interval).
[i]Random effect not significant in final model.

or tapped. No overall protective effect was observed from LEV in flour mills. Only for ingredient producers, where LEV was observed more frequently (54% of measured situations), a significant effect on flour dust exposure was observed.

DISCUSSION

In this paper we describe a comprehensive measurement database containing detailed information on exposure levels to flour dust, wheat allergens and fungal α-amylase for all four major flour processing industries in the Netherlands. The levels found in this study show no trend in exposure compared to previous Dutch studies (Houba *et al*., 1996b, 1997a, b) and generally are comparable (Brant *et al*., 2005; Bulat *et al*., 2004; Cullinan *et al*., 2001) or somewhat lower (Elms *et al*., 2006) to what is found in recent studies in other countries. Some caution has to be taken when comparing results of different countries since sampling methods and analytical methods might vary. In addition, the organization of the industry, especially the baking industry, varies widely between countries, creating differences in job types and work characteristics. Finally, large differences in dust contents with respect to the presence of wheat allergens (Burstyn *et al*., 1999) and/or additives (e.g. enzymes) can be expected.

A small part (10%) of our measurements for traditional bakeries had a sampling time of half a shift (4 h). Excluding this data did not change the final exposure models. This is reassuring and is likely due to the fact that work is very cyclical (same activities are repeated most of the shift).

In general, the database provides detailed baseline estimates of exposure that can be used to evaluate the impact of the covenant by comparison with a post intervention exposure survey. The fact that the measurement scheme was elaborate, taking substantial numbers of samples for each job/task combination, a large variety of companies and repeated measurements over a time span of several months implies that our database contains exposure information on the majority of the potential exposure situations encountered in these sectors. Therefore we believe the models provide good individual estimates of exposure among workers in these sectors. The information on variance components can be used to optimize the measurements schemes to evaluate and quantify changes in exposure due to interventions (Lampa *et al*., 2006; Lazovich *et al*., 2002a).

The models generated in our study performed moderately in explaining total variability in our

Table 5. Estimates of model variables in final mixed effects model of the log transformed exposure to flour dust, wheat allergens and fungal α-amylase among flour millers

Model variables (fixed effects)		k[c]	Flour dust		Wheat allergen		α-amylase	
			β	*P*-value	β	*P*-value	β	*P*-value
Intercept[a]			0.00	0.99	1.05	0.33	−0.27	0.80
Jobs[b]	Quality controller	20	0.21	0.76	0.79	0.51	1.33	0.27
	Cleaner	19	1.98	0.00	1.80	0.16	2.24	0.09
	Foreman/boss	19	0.69	0.31	1.12	0.35	2.51	0.03
	Mill operator	24	1.98	0.00	2.35	0.05	3.16	0.01
	Operator bagging	18	1.88	0.01	2.82	0.02	2.07	0.10
	Storage worker	35	1.98	0.00	3.55	0.00	1.69	0.17
	Operater (general)	34	0.88	0.19	1.11	0.36	3.14	0.01
	Maintenance worker	10	0.82	0.20	0.42	0.72	1.37	0.23
	Loader/unloader	4	1.66	0.03	1.55	0.23	1.78	0.16
	Chauffeur	4	0.17	0.84	2.11	0.17	1.24	0.41
	Silo builder	5	0.74	0.52	1.01	0.58	—	—
Tasks	Cleaning	78	0.39	0.08	0.73	0.06	0.85	0.08
	Storage work	24	−0.97	0.01	−1.19	0.05	—	—
	Unloading grain	17	−1.46	0.00	−2.09	0.00	—	—
	Cleaning grain	17	−1.42	0.00	−1.59	0.02	—	—
	Loading/unloading	27	—[d]	—	−1.03	0.03	—	—
	Mixing	18	—	—	—	—	1.46	0.02
Var_b_C (CI)[e]			[h]		[h]		[h]	
Var_b_w (CI)[f]			1.11 (0.66–1.57)		2.36 (1.21–3.50)		[h]	
Var_w_w (CI)[g]			0.57 (0.38–0.93)		1.41 (0.88–2.61)		[h]	
Total explained variability			29%		22%		15%	

[a]The intercept gives the exposure performing an office job, not performing any of the tasks in the model.
[b]Job office worker is reference group.
[c]Number of observations with factor present.
[d]Not in model, not significant at the α = 0.10 level.
[e]Variance component between companies (confidence interval).
[f]Variance component between workers (confidence interval).
[g]Variance component within workers (confidence interval).
[h]Random effect not significant in the final model.

populations. Overall the exposure models explained a significant proportion of between company and between worker variability. The explained day to day variability, which for all sectors was a significant part of total variability, is considerably lower. Earlier work on exposure in bakeries and flour mills reported a smaller relative contribution of within worker component to total variability (Burdorf *et al*., 1994; Nieuwenhuijsen *et al*., 1995a, b). However, the different approaches in sampling design and grouping makes detailed comparisons between studies difficult.

The fact that our models are poor in explaining day to day variability is related to the fact that frequency and time spend on activities performed was not taken into account, which is likely to be an important source of day to day variability. Other studies that take into account the time spend on different activities perform better and explain up to 70% of total dust exposure variability (Burstyn *et al*., 1997, 1998). Results in explained variability were comparable for dust and wheat allergen exposure, whereas for fungal α-amylase the explained variability was much lower (except for ingredient producers). This outcome may be explained by the fact that fungal α-amylase exposure is highly dependent on the ingredients used and the α-amylase concentration in that ingredient, two variables that were not available from our database. For ingredient producers this factor is closely associated with the task performed, therefore the model for this sector explain more variability for fungal α-amylase.

We have collected questionnaire information on jobs and tasks for the total population in the four sectors (~10 000 workers). This information in conjunction with the exposure models described in this manuscript enables us to generate individual exposure predictions for the total population at risk in the Netherlands. These can be used for the predictive diagnostics work in the context of the health surveillance system as described by Suarthana *et al*. (2005). The predictions can also serve as background

Table 6. Estimates of model variables in final mixed effects model of the log transformed exposure to flour dust, wheat allergens and fungal α-amylase among baking ingredient production workers

Model variables (fixed effects)		k[c]	Flour dust		Wheat allergens		α-amylase	
			β	*P*-value	β	*P*-value	β	*P*-value
Intercept[a]			−1.93	0.02	−0.85	0.56	0.92	0.54
Job[b]	Quality control	13	2.03	0.03	2.75	0.09	1.28	0.45
	Production worker	11	1.43	0.12	3.70	0.06	3.86	0.07
	Foreman/boss	4	1.06	0.33	1.69	0.34	1.75	0.38
	Operator bagging	20	2.42	0.01	2.42	0.11	1.01	0.53
	Storage worker	13	1.25	0.17	0.23	0.88	2.52	0.14
	Maintenance worker	2	3.09	0.02	–[e]	—	3.62	0.13
	Weigher	6	3.83	0.00	2.77	0.12	5.29	0.01
	Dumper (ingredients)	19	3.50	0.00	3.63	0.02	5.18	0.00
	General operator	16	2.04	0.02	2.00	0.20	3.24	0.05
	Loader/unloader	3	2.49	0.00	0.44	0.79	3.29	0.05
Tasks	Cleaning	30	0.98	0.00	—	—	—	—
	Weighing ingredient	16	0.88	0.05	2.11	0.00	—	—
	Packing pallets	19	–[d]	—	2.11	0.00	—	—
	Grease/paste production	13	—	—	−4.02	0.00	−4.20	0.00
	Mixing ingredients	9	—	—	—	—	1.88	0.06
Total explained variability[f]			37%		32%		31%	

[a]The intercept gives the exposure performing an office job, not performing any of the tasks in the model.
[b]Office workers are reference group.
[c]Number of observations with factor present.
[d]Not in model, not significant at the α = 0.10 level.
[e]No wheat analysis results for this job.
[f]No random effects were significant in final model.

Table 7. Impact of identified control measures and other determinants on exposure to flour dust for traditional and industrial bakeries

Task	Control measure of interest	Use	Traditional bakeries		Industrial bakeries	
			N (*k* = 200)	β (*P*-value)	N (*k* = 381)	β (*P*-value)
Sprinkling flour	Use of substitutes for dusting flour[a]	No sprinkling of flour	106	−0.39 (0.01)	314	−0.36 (0.08)[d]
		Use of substitutes	41	−0.17 (0.40)	30	−0.82 (0.00)[d]
		No use of substitutes	51	[b]	29	[b]
Dumping of flour	Use of closed silo and no bagged ingredients	No dumping of flour	57	−0.68 (0.00)	245	−0.51 (0.00)
		Closed silo	14	−0.43 (0.10)	12	−0.36 (0.25)
		Silo open and/or bags	129	[b]	124	[b]
Cleaning	Use of vacuum cleaner	No cleaning	—	[c]	238	−0.09 (0.46)
		Use of vacuum cleaner	—	[c]	33	−0.37 (0.08)
		No use of vacuum cleaner	—	[c]	109	[b]

N = # measurements; *k* = total number of observations in that sector.
[a]Use of oil, dust-free flour and/or stainless steel worktables.
[b]Reference group.
[c]No data available on this control measure for this sector.
[d]Only use of stainless steel table was observed.

information for occupational health physicians and hygienists to obtain a general idea of a workers average exposure. Although the models only explained a relatively small proportion of exposure variability, we believe the exposure predictions represent an essential part of the health surveillance system. The value of exposure information in diagnostic and prognostic rules has been shown in earlier work on laboratory animal workers (Meijer *et al.*, 2002, 2004).

The third aim of this paper was to obtain insight into the state of the art of control measures and, where possible, evaluate the effect of control measures currently in place. The complex of tasks and presence of

Table 8. Impact of LEV on exposure to flour dust for all four flour processing industries

Use of LEV	Traditional bakeries		Industrial bakeries		Flour mills		Bakery ingredient producers	
	N (k = 200)	β (P-value)	N (k = 381)	β (P-value)	N (k = 203)	β (P-value)	N (k = 126)	β (P-value)
Yes	29	−0.30 (0.18)	46	0.26 (0.14)	108	−0.08 (0.83)	68	**−0.82 (0.00)**
No	171	[a]	335	[a]	95	[a]	58	[a]

[a]Reference group.

a wide-range of exposure sources made it difficult to identify and evaluate potential control measures. A disappointing number of effective control measures were identified. When control measures were present their use was often limited to a few cases or control measures were not consequently introduced in all tasks. This strongly limited the power of this study with respect to evaluation of control measures. Furthermore, the effect of a control measure on exposure during a single short-term task may be obscured in our analysis of shift-based measurements. Nevertheless, the analysis presented in this paper provides conclusive information for a limited number of control measures. The lack of data caused by limited use of control measures in all four sectors is, in itself, an important conclusion. It suggests that more emphasis should be placed on the introduction and maintenance of control measures in these sectors.

Our analysis reveals a rather low reduction effect when the dusting flour is substituted, based on 8 h time weighted average exposure. This is contradictory to what was found by Burstyn *et al*. (1997, 1998) that showed a 30-fold decrease in exposure when substituting dusting flour with oil. This discrepancy could be explained by the fact that substitution was often 'partially' introduced; in almost all cases substitutes were introduced whilst dusting flour was still used in part of the production process. It is also likely that the effect was underestimated in this study since we pooled several substitutes into one category (less dusty flour and oil) which are probably not equally effective. Unfortunately the low number of cases in which we observed these substitutes did not allow separate analysis. Nevertheless the results suggest that elimination of dusting flour, as it is currently performed in bakeries in the Netherlands, will only result in a small reduction of TWA exposure. Studies in other sectors have also shown disappointing reduction in exposure levels due to the substitution of dusty products with less dusty materials (Vermeulen *et al*., 2000). Our evaluation showed that control measures introduced during weighing of ingredients, especially limiting the use of bagged flour products and the enclosure of silo's (when dumping flour), strongly decrease exposure. Observational information from the field suggests that training of workers in dust-free work practices (no shaking of bags/silo-hose, use of a bag compressor, wet cleaning instead of dry, etc.) will reduce peak exposures.

Data obtained during walk-through surveys indicate that, with some exceptions, not much attention is given to LEV systems in the bakeries that participated in this study. Integrated LEV systems in flour mills often had an insufficient capacity to reduce dust emissions. LEV only had a significant effect on flour dust exposure in the baking ingredient producing companies. This sector often applied advanced LEV systems for various processes and activities.

Evidence is available from the literature showing significant reductions in worker exposure due to the introduction of LEV systems. For example, LEV fitted or integrated on equipment may produce reductions of >90% (Croteau *et al*., 2002, 2004; Gressel, 1997). However, the protective effect is limited and highly depends on the way it is installed and used by the workers (Lazovich *et al*., 2002b). Our results clearly indicate that more attention should be paid to proper use and maintenance of LEV in the various flour processing sectors.

Information obtained on control measures will be used to optimize the intervention scenarios that will be implemented in the different sectors. Communication of proper control measures to workers will for a large part be based on a recently published dust control manual for bakery sectors (Goede *et al*., 2004). This manual was compiled using the contextual information gathered during the exposure measurements and walk-through surveys as described in this paper.

In conclusion, the results described in this paper will be used to underpin the covenant with flour processing branches. A broad range of exposure models were developed enabling the prediction of average exposure estimates based on job and tasks performed for a large population of workers in all major flour processing sectors in the Netherlands. The information obtained from this study will be used in the sector wide health surveillance system. A disappointing number of effective control measures were identified, indicating the importance of introducing adequate control measures in these sectors in the Netherlands.

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