

Original Article

Estimation and Validation of Flour Exposure in Bakeries in Alberta, Canada

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Abstract

Objectives: In epidemiological studies of work-related ill-health only current exposures can, at best, be measured. Previous exposures may be estimated using contemporaneous hygiene records or published data. This study aimed to create a job exposure matrix for exposure in bakers for use in an ongoing cohort study.

Methods: A systematic review was conducted of English language publications on exposures in bakeries. All publications that appeared to contain quantitative measures of exposure to flour dust, wheat allergen, or fungal α -amylase were read independently by two investigators and relevant data extracted. A third investigator reviewed these data and publications were retained that reported full-shift exposures to inhalable dust, wheat allergen, or α -amylase, and for which geometric means (GMs) were given or could be estimated. For each study, the number of sampling results contributing to each GM was recorded together with information on task, bakery size, product, filter type, sampling head, the country in which the study was conducted, and the estimated year of sampling. Multivariable models were elaborated for each exposure using a linear mixed effects approach. The predictive capacity of the model for inhaled particles was tested against samples collected in eight Alberta bakeries. The capacity of exposure intensity, estimated from each of the three models, to predict sensitization was tested against skin prick testing (SPT) for bakery allergens in bakers currently employed in Alberta.

Results: One thousand three hundred and ninety-seven publications were identified through the systematic search, of which 27 had data used to create one or more of the predictive models. Weighted GMs were used as outcome variables. For inhalable dust, task, bakery size, type of sampling head, and year of sampling contributed to the final model. For wheat allergen and α -amylase, task, bakery size, sampling head, and year of sampling again contributed. Product (bread rather than confectionary or mixed products) was also important in these two latter measures. The model for inhalable dust was used to predict the concentration in 33 samples from Alberta bakeries. Overall, 91% of observed samples had 95% confidence intervals (CIs) overlapping the 95% CIs of the predicted

values. A model including the Alberta samples found no effect attributable to Alberta provenance. Using this model for inhalable dust and the models developed solely from the literature for wheat allergen and α -amylase, a positive SPT for bakery allergens in 57 bakers recruited for this study was significantly related to log cumulative exposure for each of the three outcome variables and to log exposure intensity for wheat allergen and α -amylase.

Conclusions: The exposure models developed from the literature provide useful estimates of exposure. Calibration of the models against locally collected samples may be useful for countries poorly represented in the modeling dataset.

Keywords: bakery; flour; job exposure matrix; sensitization; systematic review; validation

Introduction

Working with flour in bakeries has long been known to be related to symptoms of rhinitis and asthma (Brant, 2007), with skin prick testing (SPT) for IgE-mediated sensitization to flour and other bakery allergens such as fungal α -amylase providing indication of bakery-specific allergens (Musk *et al.*, 1989; Houba *et al.*, 1996; Nieuwenhuijsen *et al.*, 1999; Gautrin *et al.*, 2000; Cullinan *et al.*, 2001). While sufficient is known about the risks of such exposure, prevention has proved difficult, with little indication of decreases in exposure in either the UK (to 2003) (van Tongeren *et al.*, 2009) or the Netherlands (to 2005) (Meijster *et al.*, 2007). In Alberta, Canada, there is a proposal to adopt the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 0.5 mg/m³ inhalable dust (rather than the current occupational exposure limit (OEL) of 0.5 mg/m³ for total dust): setting such limits is a provincial responsibility but the ACGIH limit is usually adopted. In this instance, there was concern about the proposed change among employers who were finding it difficult to comply even with the current OEL. To put these issues into the local context, an exposure study was set up, in 2013, by Alberta Labour (AL) (the provincial occupational health prevention agency) to assess worker exposure to flour dust in Alberta commercial bakeries. Overall, the total dust exposures in the bakeries assessed were found to be more than double the OEL currently in place. In order to support change in enforcement, and for the adoption of the ACGIH TLV, it was felt important to demonstrate whether such over-exposure was associated with any indicator of ill-health. As such, a study has been undertaken of health in a cohort of trainees joining bakery courses in the two large colleges of technology within the province. These trainees, still being followed-up at six-monthly intervals, included many who had had flour exposure before joining the course, some over many years. It was not possible to measure

such prior exposure retrospectively and there was little local data from which to estimate earlier exposure. As such, it was decided to use published data from studies carried out elsewhere to model exposure over the last 30 years, and to use this to estimate cumulative exposure before recruitment into the study.

Modeling of exposure information extracted from the literature has been used for a number of substances including formaldehyde (Lavoué *et al.*, 2007) styrene (van Rooij *et al.*, 2008), silica (Sauvé *et al.*, 2013), and lead (Locke *et al.*, 2017) but not, to our knowledge, for flour or bakery allergens. Further, the exposure data collected for AL in 2013 provided an opportunity to assess whether the model developed was relevant to the Alberta context. A concurrent cross-sectional study of experienced bakers still working in the province provided a further opportunity to test the models developed, using sensitization, as indicated by SPT, as a biomarker of effect. Although the main purpose of developing these models was to enable a dose-response analysis of health effects in the bakery trainee cohort, it was felt that characterization of high exposure processes would also help to focus prevention among Alberta bakeries that were finding compliance difficult. Further, since the models were derived from exposures from published studies without restriction as to country of origin, the models might be of value beyond Alberta.

Methods

Development of the exposure database

Peer-reviewed articles in the published literature were found using a search strategy containing bakery-related terms (see [Supplementary Material 1](#) in the [Supplementary Material](#), available at *Annals of Work Exposures and Health* online for details of the search strategy) applied to electronic databases namely Medline, Embase, ISI Web of Science, CINAHL, SCOPUS, and Google Scholar. Additional references

were identified by: hand-searching reference lists of all included reports; forward citation searching in Scopus; references cited in related Google scholar articles; searching conference proceedings. All papers in which the abstract implied that they might contain quantitative data on flour exposure in bakeries were examined as full texts. There was no restriction as to the date of publication: the last search of all databases was conducted on 29 January 2017. A standardized extraction form was developed and used to extract data from published articles ([Supplementary Material 1](#) in the [Supplementary Material](#), available at *Annals of Work Exposures and Health* online). This included the year of publication and year of sampling (if given), country of sampling and, where available, sampling equipment, flow rate, area or personal sampling, type of business, job task performed, products of the bakery, number of samples taken, substances sampled, and the results of sampling [arithmetic or geometric means (GM) and standard deviations, median and ranges, reported single values]. All papers underwent two independent reviews. Where discrepancies were found these were resolved through discussion.

The extracted data were then organized to a classification, standard across publications, of processes and products, and of potential confounders (size of bakery, date of sampling, type of sampling head, type of filter, and country). These data were recorded separately for three exposures, inhalable dust, wheat allergen, and fungal α -amylase. Before the final analysis, each publication was reviewed by a third investigator to confirm the relevance of the data extracted. Only personal samples with sampling period of at least 3 h were retained for statistical modeling.

Exposure data used for validation of the inhalable dust model

An occupational hygiene consulting company, commissioned by the Alberta Government, carried out whole shift sampling during representative shifts of worker exposure to both total and inhalable dust in Alberta bakeries in 2013. Personal sampling was carried out at eight work sites, comprising one large, two medium, and five small commercial bakery facilities. Only the inhalable dust samples were used in the validation phase described here: these measurements were made using an Institute of Occupational Medicine (IOM) sampling head and polyvinyl chloride (PVC) filter with a flow rate of 2 l/min. Analysis was carried out by an American Industrial Hygiene Association accredited laboratory. There were 33 such results included in the hygiene report, which gave values by worker position (bakers, mixers, other)

product and size of establishment. These data were made available to the study team by AL and the sampling results are referred to in the validation analysis as AL exposure data. Although this hygiene report is not in the public domain, requests for more information on methods may be made by contacting the authors of the current report.

Exposure and outcome data used for the validation by SPT sensitization

Eight bakeries in Alberta agreed to take part in a cross-sectional study to collect information from current workers on history of work with flour exposure since leaving school, and SPT for 10 bakery associated allergens and for 6 common environmental allergens, together with a positive and negative control ([Supplementary Material 2](#) in the [Supplementary Material](#), available at *Annals of Work Exposures and Health* online). Only one of these bakeries was included also in the AL exposure study. Questionnaires on job history and potential confounders (including family history of allergy, smoking history, age and gender) were completed and SPTs carried out at the worksite during the working day. For these tests, a wheal of ≥ 3 mm was considered positive ([Bousquet et al., 2012](#)). A baker was considered to show sensitization to allergens in the bakery environment if they were positive to one or more bakery allergens and to be atopic if they were positive to one or more common environmental allergens.

Statistical methods

GMs were used throughout the analysis. Where only arithmetic mean (AM) and standard deviation (ASD) were published, the GM was estimated as $AM/\sqrt{(1 + ASD^2/AM^2)}$ as in [Lavoué et al. \(2007\)](#). Where only medians or single observations were reported, these were treated, as by [Lavoué et al.](#), as GMs.

A linear mixed effects model was adopted, using the Stata program `gllamm`, for modeling the data from the literature, with the study identifier entered as a random effect and robust variance estimates. The dependent variable in each model was taken as the natural log of the GM, measured as $\mu\text{g}/\text{m}^3$. The logs of the GM were frequency weighted by the number of samples summarized.

As in [van Rooij et al. \(2008\)](#), time trends were first inspected visually to identify years in which exposure changes occurred and fitting a 'broken stick' model with either two or three time variables used to model different rates of change over the years since the first reported sample. The `mksplines` function within Stata was used

to confirm the breakpoints where appropriate. Where the year of sampling was not reported, the year of publication minus 4 years was taken as an estimated year of sampling, based on the median lag for papers where both dates were given.

Each exposure or measurement factor was first entered into the model in a univariate analysis using the categories shown in Table 1. All factors were then entered together into a multivariable model. Factors were dropped but re-entered in turn to determine, using a Wald test, whether they added (with $P < 0.05$) to the model developed to that point. Because of important differences in estimation observed in previous work (Kenny *et al.*, 1997), type of sampling head was included in every multivariable model. For wheat allergen and α -amylase, where there were a limited number of studies, some categories were collapsed

to allow a multivariable model to be fitted. A final model was thus elaborated for each exposure.

The final gllamm model for inhalable dust was used to predict exposures for the bakeries included in the AL field survey. This was done using the prediction algorithm in the STATA program gllamm (gllapred) to predict these new observations from a new study (that is, one not included in construction of the prediction model). The command ci_mu_marg was used to produce the 95% and 99% confidence intervals (CIs) of this prediction by simulation, which was defaulted on 1000 repetitions. The proportion of observations falling within the prediction CIs was calculated and size and direction of deviation between the observed and predicted exposures examined. To allow for sampling variability in the validation samples (Hornung *et al.*, 1994), sampling error

Table 1. GM from the literature review by study characteristics: inhalable dust, wheat allergen, and α -amylase.

Task	Inhalable dust				Wheat allergen				Fungal α -amylase			
	GM $\mu\text{g}/\text{m}^3$	N ^a	N ^b	N ^c	GM $\mu\text{g}/\text{m}^3$	N ^a	N ^b	N ^c	GM ng/m^3	N ^a	N ^b	N ^c
Oven tasks	1834.17	11	1481	19	19.51	7	1197	16	0.55	6	1004	16
Confectionary tasks	937.73	8	238	9	44.13	5	229	6	0.28	4	161	8
Weighing/Mixing	4930.75	11	867	24	37.21	3	176	6	6.89	4	167	9
Dough former	3078.43	4	267	7	40.98	2	73	2	0.64	2	26	3
Other production	809.57	10	559	26	24.60	5	476	24	0.39	4	309	19
Carried out all tasks	2951.54	6	644	17	22.70	2	236	10	3.49	5	375	15
Non-production	479.00	14	637	19	12.51	7	510	18	0.33	6	288	12
Bakery Size												
Small	1841.71	8	848	16	8.55	5	668	11	0.60	5	516	8
Medium	1513.16	6	598	14	6.60	2	435	12	0.35	4	258	8
Large	1634.14	10	1931	49	31.21	7	1706	51	1.09	7	1204	49
Multiple	3851.96	7	1320	42	52.48	1	88	8	4.48	3	352	17
Product												
Bread	2816.32	22	1518	59	27.87	8	890	33	2.12	9	612	32
Confectionary	2607.66	14	1519	38	19.53	8	943	22	1.37	7	999	24
Mixed	1488.28	10	1660	24	21.83	8	1064	27	0.71	6	639	26
Filter												
Cellulose/Other	4147.42	6	654	25	4.99	1	148	2	0.47	1	27	3
Glass Fiber	4164.05	6	929	28					3.57	2	291	11
Teflon	1324.97	9	3114	68	29.90	9	2749	80	1.12	7	2012	68
Sampling Head												
7-hole	5104.48	4	663	25	121.02	2	440	22	2.50	2	529	41
PAS6	1262.62	9	3197	62	5.37	8	2457	60	0.74	6	1610	30
IOM	3925.79	8	837	36					3.57	2	291	11
Place												
UK	4675.02	8	1250	39	138.15	1	352	14	2.09	4	659	47
Europe	1443.34	10	2940	64	5.11	6	2022	48	0.83	4	1372	22
North-America	3634.89	1	88	8	52.48	1	88	8	8.46	1	88	8
South-Africa	715.20	2	419	10	6.60	2	435	12	0.13	1	211	5

N^a, number of studies; N^b, number of samples; N^c, number of means.

using the IOM head (Esmen and Johnson, 2001) (Health and Safety Executive UK) and measurement error in the new observations was estimated at 10% of the log of GM and CIs constructed for each observation. The number of overlapping CIs (around observed and predicted values) was computed. The modeling was then repeated including the 2013 Alberta samples together with a binary factor (Alberta/elsewhere) to determine whether the Alberta samples reported significantly different exposures than those from the published literature.

For the validation by the effect biomarker of skin sensitization, cumulative exposures to inhalable dust, wheat allergen, and α -amylase were calculated from the detailed information on each job that had been collected from experienced bakers recruited for this part of the study. The time in each task with each product reported was weighted by the task, product, and date parameters (where appropriate) and summed for all employment with flour since leaving school. As size of establishment was known only for the current employer, this was assumed to be the same for all flour exposure for that individual. For inhalable dust the model including the Alberta data was used to compute cumulative exposure. Logistic regression, using GLM within Stata, was used to assess the relation between the log estimated cumulative exposures (to inhalable dust, wheat allergen, and fungal α -amylase) and log intensity (cumulative exposure/duration) and a positive SPT to bakery allergens. Possible confounders considered were age, gender, ever smoked (one cigarette per day for at least 1 year), and atopy, either from family history (allergic condition in a first degree relative) or a positive SPT to one or more common environmental allergens. Only confounders reaching $P < 0.05$ in the univariate analysis were considered in the multivariable models. These examined first whether the estimated cumulative exposures were related to a positive SPT having allowed for selected confounders, and second, whether intensity of exposure was related to SPT results, in a model that included duration. The contribution of a single factor, or group of factors, was assessed with the Wald test and with $P < 0.05$.

Results

Twenty-seven papers among 1937 publications identified through the search strategy were found to have exposure data that could contribute to this exercise. These are listed in [Supplementary Material 3](#) in the [Supplementary Material](#) (available at *Annals of Work Exposures and Health* online), annotated by the models in which results from the paper were included. Twenty-one studies provided 135 GMs for modeling inhalable dust (98 given

as GMs, 18 estimated from medians, and 19 from arithmetic means or single values). For wheat allergen, there were 10 studies with 83 GMs, all reported as such in the publications. Ten studies provided 94 GMs for fungal α -amylase, of which 71 were reported directly, 11 estimated from reported medians, and 12 from single observations.

The weighted GMs by task, bakery size, product, filter, sampling head, and country in which the study was conducted are given, together with the number of studies, observations (GMs), and number of samples, in [Table 1](#) for each exposure component. The univariate and multivariable models for inhalable dust taken from the literature are shown in [Table 2](#). In the univariate analyses, all levels of all factors had a 95% CI that excluded 0 when compared to the reference category except for multiple bakeries of different sizes compared with large, bread and confectionary (compared to mixed) as a product, cellulose/other filters compared with Teflon, and the IOM sampling head compared with the PAS6. The two variables reflecting year of sampling showed a slight decrease in inhalable dust in more recent years. Europe and South Africa have been grouped together because of the similarity of methods and overlap of investigators between the Netherlands and the two South African studies. These studies showed the lowest concentrations. The product produced did not contribute to the final model which is also shown in [Table 2](#) and only the time variable reflecting years since 1990 was retained. High β coefficients were found for weighing and mixing, oven tasks and dough forming, for small rather than large bakeries and for studies using a 7-hole sampling head. The predicted against observed values for the final model are shown in [Fig. 1](#).

[Table 3](#) shows the parallel results for wheat allergen. In the univariate analysis, for size of bakery, only studies based on small and multiple bakeries of different size reported levels higher than in large bakeries and, again, neither bread nor confectionary differed from mixed products. No study of wheat allergen reported using an IOM sampling head or glass fiber filter, but higher results were found with the 7-hole than PAS6 head. The type of filter used did not contribute, and results did not differ by the year of sampling. Results from the UK and North America were higher than from South Africa/Europe. In the multivariate model, with product collapsed to binary contrast of bread against other products, filter type did not contribute. Higher levels were found particularly with weighing and mixing and dough forming, in small and medium sized bakeries, when the product was bread and in studies using a 7-hole sampling head. The two time variables suggested an increase in concentration from 1990 with a decrease since 1996.

Table 2. Inhalable dust: univariate and multivariable models using data from the literature.

	Univariate			Multivariable		
	β	SE	CI (95%)	β	SE	CI (95%)
Task						
Oven tasks	1.56	0.15	1.25–1.87	1.44	0.18	1.09–1.78
Confectionary tasks	0.98	0.26	0.47–1.49	0.88	0.29	0.31–1.45
Weighing/Mixing	1.99	0.20	1.60–2.38	1.98	0.20	1.59–2.37
Dough former	1.37	0.21	0.96–1.79	1.37	0.21	0.96–1.79
Other production	0.56	0.13	0.30–0.82	0.56	0.13	0.30–0.82
Carried out all tasks	1.05	0.28	0.49–1.60	1.05	0.28	0.49–1.60
Non-production	rc	rc	rc	rc	rc	rc
Bakery size						
Small	0.61	0.09	0.43–0.79	0.26	0.09	0.08–0.45
Medium	-0.34	0.11	-0.55 to -0.13	-0.49	0.10	-0.69 to -0.28
Multiple	0.05	0.07	-0.08–0.18	-0.30	0.10	-0.49 to -0.10
Large	rc	rc	rc	rc	rc	rc
Product						
Bread	0.36	0.33	-0.30–1.07			
Confectionary	0.03	0.30	-0.55–0.61			
Mixed	rc	rc	rc			
Filter						
Cellulose/Other	0.53	0.37	-0.19–1.68			
Glass Fiber	0.95	0.37	0.22–1.68			
Teflon	rc	rc	rc			
Sampling Head						
7-hole	1.19	0.22	0.76–1.61	0.71	0.15	0.40–1.01
IOM	0.68	0.36	-0.03–1.39	0.53	0.28	-0.03–1.08
PAS6	rc	rc	rc	rc	rc	rc
Place						
UK	0.73	0.38	-0.00–1.47			
North-America	0.66	0.15	0.37–0.96			
South-Africa/Europe	rc	rc	rc			
Years Since 1990	-0.06	0.02	-0.09 to -0.03	-0.04	0.02	-0.08 to -0.01
Years Since 1996	-0.10	0.03	-0.15 to -0.05			
Constant	7.37 ^a	0.18	7.03–7.72	6.40	0.14	6.12–6.67

rc denotes the reference category.

^aModel with intercept only Univariate model with intercept only: variance within studies = 0.47; between studies = 0.61 Multivariable model: variance within studies = 0.16; between studies = 0.41.

The univariate analysis for α -amylase (Table 4) showed that among tasks only weighing and mixing and 'all tasks' had higher values than non-production with differences also seen with filter and sampling head. The single North American study had higher values. In the multivariable model, where categories were again collapsed because of small numbers, a composite category of weighing, mixing and dough forming had higher exposure than non-production tasks and studies of medium sized or multiple bakeries of differing sizes had lower exposure than large bakeries. Exposure was

higher where the product was bread and where the study used a 7-hole sampling head. Exposure increased from 1990 then decreased after 1996. The time trends for the three exposures are shown graphically in [Supplementary Material 4](#) in the [Supplementary Material](#) (available at *Annals of Work Exposures and Health* online).

The predictive value of the multivariable model for inhalable dust (in Table 2) was tested by predicting values for the 33 samples taken for AL from 8 bakeries, for which information was available on task, bakery size, and sampling head. Product and filter were also known but

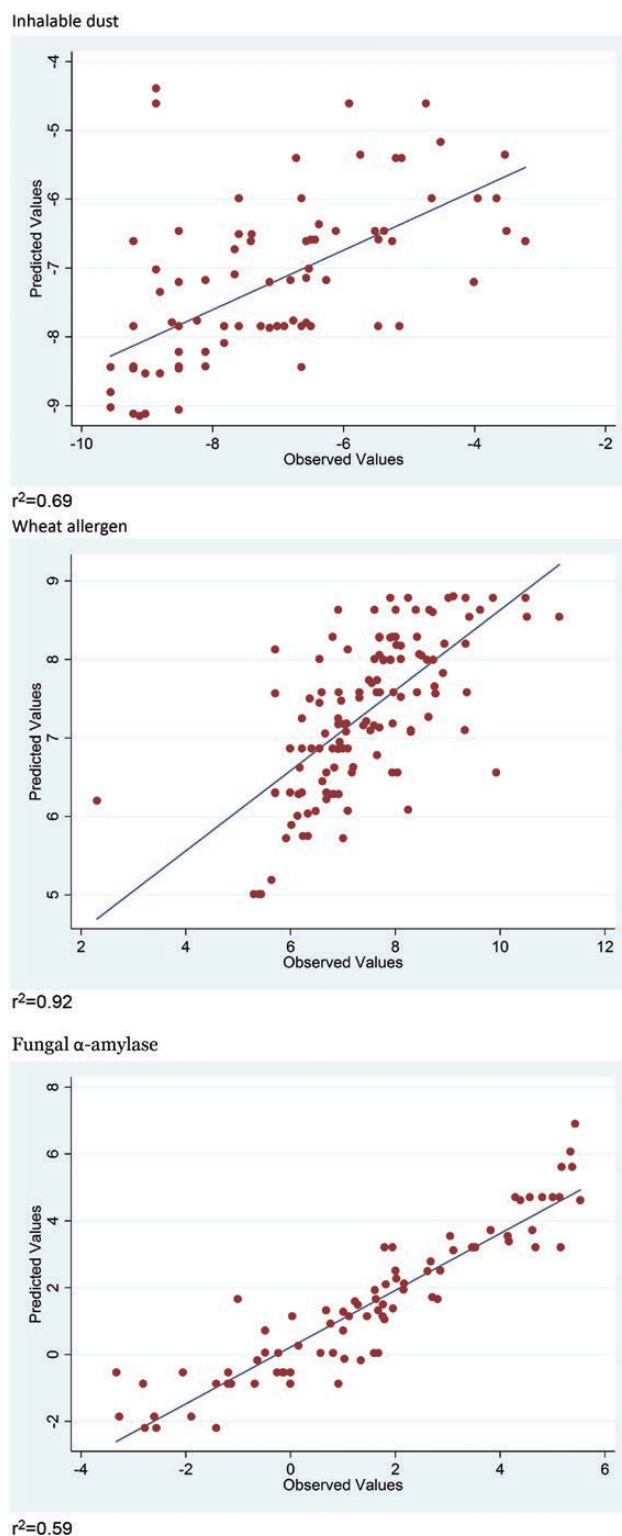


Figure 1. Observed values against predicted values of log transformed GMs for inhalable dust, wheat allergen and fungal α -amylase ($\mu\text{g}/\text{m}^3$).

Table 3. Wheat allergen: univariate and multivariable models using data from the literature.

	Univariate			Multivariable		
	B	SE	CI (95%)	β	SE	CI (95%)
Task						
Oven tasks	2.49	0.45	1.61–3.37	1.89	0.31	1.28–2.50
Confectionary tasks	1.53	0.33	0.87–2.18	1.23	0.23	0.78–1.68
Weighing/Mixing	3.40	0.48	2.47–4.33	3.52	0.46	2.61–4.42
Dough former	2.79	0.37	2.07–3.51	2.69	0.30	2.10–3.27
Other production	1.28	0.23	0.82–1.74	1.32	0.22	0.88–1.76
Carried out all tasks	2.53	0.95	0.68–4.39	1.22	0.29	0.64–1.79
Non-production	rc	rc	rc	rc	rc	rc
Bakery size						
Small	1.34	0.26	0.82–1.85	1.01	0.20	0.62–1.40
Medium	0.40	0.56	-0.70–1.49	1.24	0.57	0.13–2.34
Multiple	2.11	0.49	1.15–3.07	-2.19	0.55	-3.28 to -1.10
Large	rc	rc	rc	rc	rc	rc
Product						
Bread	0.53	0.45	-0.35–1.42	0.34	0.09	0.17–0.51
Confectionary	-0.09	0.35	-0.78–0.60	rc	rc	rc
Mixed ^a	rc	rc	rc			
Filter						
Cellulose/Other	-0.24	2.01	-3.88–4.01			
Glass Fiber						
Teflon	rc	rc	rc			
Sampling Head						
7-hole	2.87	0.67	1.55–4.19	6.66	0.15	6.37–6.95
IOM						
PAS6	rc	rc	rc	rc	rc	rc
Place						
UK	3.64	0.35	2.94–4.33			
North-America	2.10	0.35	1.40–2.79			
South-Africa/Europe	rc	rc	rc			
Years Since 1990	-0.02	0.05	-0.12–0.08	0.54	0.05	0.45–0.64
Years Since 1996	-0.03	0.08	-0.18–0.11	-0.60	0.08	-0.75 to -0.45
Constant	1.72 ^b	0.40	0.94–2.50	-3.28	0.22	-3.70–2.86

rc denotes the reference category.

^aCombined with confectionary in the multivariable model. ^bModel with intercept only Univariate model with intercept only: variance within studies = 1.25; between studies = 2.11 Multivariable model: variance within studies = 0.30; between studies = 0.02.

did not appear in the model. The predicted values, with 95% CI for the prediction, are shown in Table 5, together with the observed values both as recorded and log transformed. The mean deviation (also referred to as bias) was 0.45, with the observed mean being somewhat higher than predicted. The standard deviation of the deviations ('precision') was 101.6. Overall, 17 out of 33 (51%) of the log transformed observations fell within the 95% CI of prediction with the number increasing to 20 out of 33 (61%) in the 99% CIs (details not shown). If we assume a 10% sampling and measurement error around the log

of each observation, the CIs around the observed and predicted overlapped for 30/33 (91%). A further model was constructed including the 33 observations together with a factor reflecting the provenance of the samples (Alberta/elsewhere) (Supplementary Material 5 in the Supplementary Material, available at *Annals of Work Exposures and Health* online). No univariate effect was seen for Alberta ($\beta = 0.07$, 95% CI -0.25–0.30) and this factor did not appear in the final model.

The final step was to compute cumulative exposures and mean intensity for each of the components and

Table 4. Fungal α -amylase: univariate and multivariable models using data from the literature.

	Univariate			Multivariable		
	B	SE	CI (95%)	β	SE	CI (95%)
Task						
Oven tasks ^a	0.67	0.40	-0.10–1.45	0.62	0.32	-0.01–1.25
Confectionary tasks ^a	0.18	0.30	-0.42–0.77			
Weighing/Mixing ^b	1.97	0.22	1.53–2.40	1.85	0.17	1.51–2.19
Dough former ^b	0.62	0.58	-0.52–1.76			
Other production ^a	0.52	0.29	-0.04–0.09			
Carried out all tasks ^a	0.89	0.26	0.38–1.39			
Non-Production	rc	rc	rc	rc	rc	rc
Bakery Size						
Small	0.22	0.35	-0.46–0.90	0.22	0.29	-0.35–0.79
Medium	-0.29	0.41	-1.09–0.50	-0.56	0.14	-0.84 to -0.28
Multiple	-0.04	0.20	-0.43–0.34	-0.59	0.21	-1.01 to -0.17
Large	rc	rc	rc	rc	rc	rc
Product						
Bread	0.50	0.43	-0.34–1.34	0.58	0.26	0.07–1.10
Confectionary	-0.21	0.20	-0.61–0.19	rc	rc	rc
Mixed ^c	rc	rc	rc			
Filter						
Cellulose/Other	-0.24	0.03	-0.29 to -0.18			
Glass Fiber	1.47	0.13	1.21–1.73			
Teflon	rc	rc	rc			
Sampling Head						
7-hole	0.81	0.40	0.04–4.59	1.61	0.25	1.12–2.09
IOM	1.56	0.19	1.18–1.93	0.88	0.60	-0.29–2.06
PAS6	rc	rc	rc	rc	rc	rc
Place						
UK	0.63	0.61	-0.57–1.82			
North-America	2.17	0.37	1.45–2.89			
South-Africa/Europe	rc	rc	rc			
Years Since 1990	-0.01	0.06	-0.12–0.10	0.51	0.09	0.33–0.68
Years Since 1996	-0.12	0.08	-0.27–0.03	-0.66	0.13	-0.91 to -0.41
Constant	-7.33 ^d	0.34	-8.00 to -6.65	-10.65	0.40	-11.45 to -9.86

rc denotes the reference category.

^aCombined to a single category (oven tasks, confectionary tasks, other production, all tasks) for multivariable analysis. ^bCombined to a single category (Weighing/mixing/dough forming) for the multivariable analysis. ^cCombined with confectionary for the multivariable analysis. ^dModel with intercept only. Univariate model with intercept only: variance within studies = 0.72; between studies = 1.04. Multivariable model: variance within studies = 0.53; between studies = 0.23.

to use these to predict a positive SPT in the 57 bakers recruited for this study from Alberta bakeries. Among these, 10 (17.5%) had a positive SPT for bakery allergens. The median age was 41.5 years, 19 (33.3%) were female, 12 (21.1%) had, at some point, smoked at least one cigarette a day for at least a year, 31 (54.4%) reported that at least one first degree relative had an allergic condition, and 22 (38.6%) had a positive SPT for a common (non-bakery) allergen. Age, sex, and smoking were not related to SPT result: the only

potential confounder meeting the level ($P < 0.05$) for inclusion was the atopy measure (SPT positive for a non-bakery allergen).

The regression analysis (Table 6) investigated the relation between exposure indices and SPT. This analysis used the model for inhalable dust containing all information (i.e. including the Alberta samples as shown in [Supplementary Material 5](#) in the [Supplementary Material](#), available at *Annals of Work Exposures and Health* online). In the univariate

Table 5. AL respirable dust measures: observed and predicted with overlapping CIs.

	Observed (GM $\mu\text{g}/\text{m}^3$)	Observed (log GM $\mu\text{g}/\text{m}^3$)	95% CI based on 10% error		Predicted	95% CI pre- dicted values		Deviation	Overlap of both CIs
	212	5.36	4.82	5.89	6.84	5.86	7.81	-1.48	Yes
	870	6.77	6.09	7.45	8.13	7.19	9.10	-1.36	Yes
	570	6.35	5.71	6.98	7.52	6.45	8.66	-1.18	Yes
	670	6.51	5.86	7.16	7.59	6.61	8.61	-1.08	Yes
	540	6.29	5.66	6.92	7.26	6.21	8.33	-0.97	Yes
	790	6.67	6.00	7.34	7.59	6.61	8.61	-0.92	Yes
	820	6.71	6.04	7.38	7.59	6.61	8.61	-0.88	Yes
	710	6.57	5.91	7.22	7.33	6.37	8.31	-0.76	Yes
	830	6.72	6.05	7.39	7.33	6.37	8.31	-0.60	Yes
	1200	7.09	6.38	7.80	7.59	6.61	8.61	-0.50	Yes
	1200	7.09	6.38	7.80	7.59	6.61	8.61	-0.50	Yes
	1600	7.38	6.64	8.12	7.59	6.61	8.61	-0.21	Yes
	1400	7.24	6.52	7.97	7.26	6.21	8.33	-0.02	Yes
	2200	7.70	6.93	8.47	7.59	6.61	8.61	+0.11	Yes
	2500	7.82	7.04	8.61	7.38	6.49	8.28	+0.44	Yes
	2700	7.90	7.11	8.69	7.38	6.49	8.28	+0.52	Yes
	1600	7.38	6.64	8.12	6.84	5.86	7.81	+0.54	Yes
	4300	8.37	7.53	9.20	7.59	6.61	8.61	+0.78	Yes
	5900	8.68	7.81	9.55	7.87	6.99	8.79	+0.81	Yes
	610	6.41	5.77	7.05	5.40	4.25	6.58	+1.01	Yes
	4700	8.46	7.61	9.30	7.38	6.49	8.28	+1.07	Yes
	5800	8.67	7.80	9.53	7.59	6.61	8.61	+1.08	Yes
	660	6.49	5.84	7.14	5.40	4.25	6.58	+1.09	Yes
	6900	8.84	7.96	9.72	7.38	6.49	8.28	+1.46	Yes
	7200	8.88	7.99	9.77	7.38	6.49	8.28	+1.50	Yes
	11,000	9.31	8.38	10.24	7.59	6.61	8.61	+1.72	Yes
	1300	7.17	6.45	7.89	5.40	4.25	6.58	+1.77	Yes
	1300	7.17	6.45	7.89	5.40	4.25	6.58	+1.77	Yes
	1300	7.17	6.45	7.89	5.40	4.25	6.58	+1.77	Yes
	5700	8.65	7.78	9.51	6.84	5.86	7.81	+1.81	Yes
	6200	8.73	7.86	9.61	6.84	5.86	7.81	+1.89	No
	1600	7.38	6.64	8.12	5.40	4.25	6.58	+1.98	No
	2100	7.65	6.88	8.41	5.40	4.25	6.58	+2.25	No
Mean	2636	7.44	7.10	7.78	6.99	6.68	7.30	0.45	

analysis, duration (total weeks working with flour) was related to SPT positivity to bakery allergens, as was cumulative exposure to each of the three flour components. Intensity of exposure to wheat allergen and α -amylase but not inhalable dust was also related to SPT. In a multivariable analysis, allowing for atopy, little effect was seen on the relation to cumulative exposure: all remained associated with a positive SPT for bakery allergens. The final analysis was to test intensity together with duration and atopy. As anticipated from the univariate analysis, duration but not intensity was important for inhalable dust. For wheat allergen intensity was somewhat more strongly associated

than duration when both were in the model, and for α -amylase, duration rather than intensity.

Discussion

The study of Alberta bakers was set up to assist the Alberta provincial government determine the risk to those exposed to flour in bakeries under their jurisdiction. Although it was clear from the 2013 hygiene study that exposures were high, it was felt that health data showing adverse effects would be more convincing to local employers than simply imposing new regulations based on data (however extensive) collected elsewhere.

The ongoing cohort study of 220 bakers recruited during training will help to demonstrate new onset sensitization and respiratory signs and symptoms, if these occur, but to interpret these and to demonstrate any dose–response relationship, it was important to have a quantitative assessment of past and on-going exposures. The exposure models developed here provide such a tool.

Although the large number of papers published on bakery exposures made this development possible, it was not always straightforward to determine which results were independent, when authors published many papers from related studies, and even within a single paper, authors seldom cross-tabulated data in a way that allowed a sample to be classified by task, product, and bakery size. A conservative approach was taken, excluding values where there was any possibility of duplication, but this may have excluded some values that might have validly contributed. Further, even within the data included for model development, there was considerable variation in the quality of the studies and the methods used to determine concentration of wheat allergen and α -amylase (see, for example, [Lillienberg et al., 2000](#)). The methods we adopted, once a study was in the dataset, assumed all were equally valid: this is almost certainly unfounded.

The availability of local data on inhalable dust in bakeries and on sensitivity to bakery allergens in those currently baking was valuable in assessing whether the models developed might be useful in this context. In the validation using observations (sampling results) from Alberta bakeries we were concerned not to regard the observations as ‘true’ error free results but had no clear guidance as how to estimate the sampling variability. [Hornung et al. \(1994\)](#) recognized the problem 25 years earlier, but without a solution other than to collect so many validation samples that it was possible to reduce variability by predicting means rather than individual observations. Accepting that variability in the observations will include both sampling and measurement error, we called on the theoretical work of [Esmen and Johnson \(2001\)](#) as well as the practical advice of the UK Health and Safety Executive to estimate a possibly conservative 10% error. Use of a different value may have affected the (high) proportion of observations in which the observed and predicted CIs over-lapped. In the event the GM of the observed observations (2.3 g/m^3) dovetailed with the only two previous North American studies we encountered. [Burstyn et al. \(1997\)](#) reported a mean of 2.1 g/m^3 for inhalable dust in Canadian (British Columbia) bakeries while [Page et al. \(2010\)](#) using a mixture of personal and area sampling, a mean of 3.0 g/m^3 , in their higher exposed (production) workers in the USA. The study sample for the SPT validation was also relatively small (with just 57

workers) and while a larger group would certainly have allowed us to say more (for example, to examine the relation of cumulative exposures to α -amylase and SPT positivity to aspergillus), the results we have presented here suggest that the models are better than total duration in predicting the SPT, used here as an effect biomarker. As such, the use of these models to estimate exposures in the much larger on-going cohort study, without the healthy worker effect potentially present in cross-sectional studies, should provide more precise answers.

In developing the models, it became clear that some of the factors were not independent, in particular the filter and sampling head, and the sampling head and the place in which the sampling was being done. Studies in Europe and South Africa very largely used the PAS6 while many elsewhere used the 7-hole or, more recently the IOM head. The degree of correlation between country and sampling head meant that it was not possible to include both in the same statistical model. Although it seems likely that at least some of the differences between countries reflects exposure control enforcement practices that would be relevant to prediction, we have chosen instead to prioritize type of sampling head as being of greater relevance to the occupational hygiene community considering the application of these models. Nevertheless, it may be helpful to calibrate these models (as done here for inhalable dust in Alberta) to see how well they fit samples taken under local conditions.

Part of the rationale for developing the exposure models was to allow estimation of past exposures. It had previously reported that, in samples taken in 1985–2003 within the UK no time trend was seen for inhalable dust ([Van Tongeren et al., 2009](#)), [Meijster et al. \(2007\)](#) commented that their samples taken in 2000–2005 did not differ from earlier samples taken in the Netherlands. In the models presented here, including data from many countries, a small decline with year since 1990 was found for inhalable dust and an increase in both wheat allergen and α -amylase from 1990 to 1996 followed by a decrease. This might, perhaps, reflect the years during which studies were conducted in different countries but for α -amylase, at least, the effect was found present even if country was forced into the model. The marked increase in concentrations of α -amylase followed by a steep decrease is consistent with other reports, with increased control after recognition of its potency as a sensitizer ([Houba et al., 1996](#); [Smith, 2004](#)). For assessing earlier exposure to this component, knowledge of the time of exposure would seem particularly important.

This paper is essentially methodological and, based as it is on published work, would not be expected to introduce new insights into the aspects of bakery work

at greatest risk. As previously reviewed (Baatjies and Jeebhay, 2013), the models show that flour exposure is greatest in weighing and mixing and in dough forming, wheat allergen in bread making and with low exposure to α -amylase in confectionary work, but the development of models for Alberta, together with the documented high exposures, may help to focus attention on education and control. While this would potentially reduce the risk to the health of those entering the trade in the Province, simulation models suggest that rigorous health surveillance strategies may be needed in addition to significantly reduce the burden of disease (Meijster *et al.*, 2011).

Supplementary Data

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

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Ethics

The research described here was approved by the Health Ethics Review Board of the University of Alberta.

Conflict of Interest

The authors declare no conflict of interest relating to the material presented in this Article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

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Online Supplementary Material

Estimation and validation of flour exposure in bakeries in Alberta, Canada.

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Supplementary materials 1: Systematic review

1) Search Strategy

The search query developed was: (Baker OR bakers OR baker* OR bakery OR pastry making OR pastry maker OR pastry arts OR confectioner OR patisserie) AND (flour OR wheat OR rye OR bread improver OR amylase OR cellulase OR xylanase OR dust).

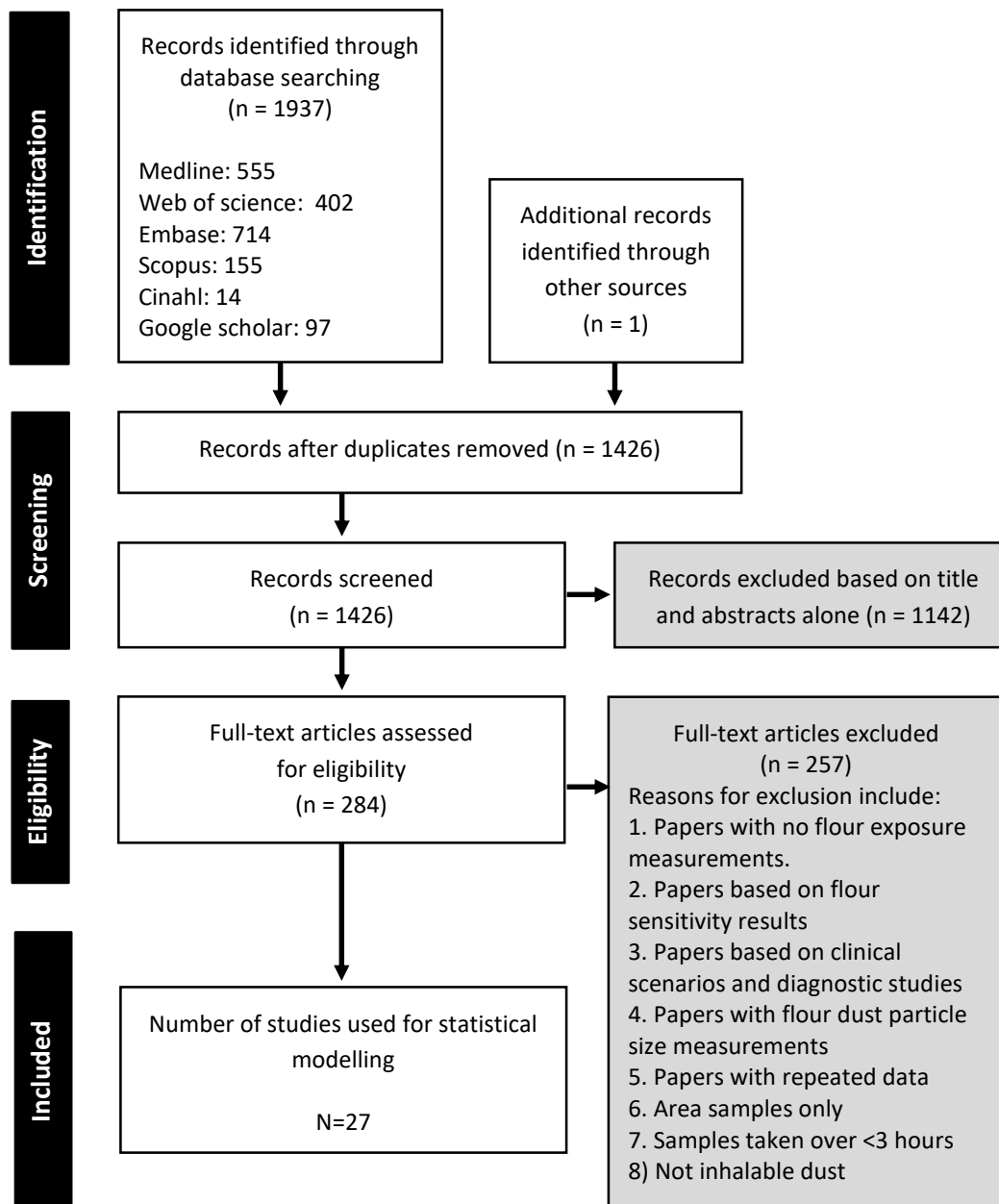
When the search query was used on Medline and limiting it to humans and the English language, numerous papers were identified.

The search query was adapted for Embase, ISI Web of Science, CINAHL, SCOPUS and Google Scholar.

2) Extraction sheet

Reference #	
Author (year)	
Date of sampling	
Sampling equipment/flow rate	
Personal or area samples	
Type of business	
Task	
Product	
Number of samples	
Substance sampled	
Geometric mean ($\mu\text{g}/\text{m}^3$)	
Standard deviation of geometric mean	
Arithmetic mean ($\mu\text{g}/\text{m}^3$)	
Standard deviation of arithmetic mean	
Median ($\mu\text{g}/\text{m}^3$)	
Range ($\mu\text{g}/\text{m}^3$)	
Country	

3) Papers identified and included



Supplementary materials 2:

A) List of the common and work place allergens included in skin prick testing

Common allergens

- Mixed grass pollens
- Mold mix (Altenarius, Aspergillus, Hormodendrum herbarum, Penicillin)
- Mite mix (Dermatophagoides pteronyssinus, Dermatophagoides farinae)
- Tree mix (Alder, Ash, Birch, Elm, Maple, Oak, Hickory, Poplar and Sycamore)
- Dog
- Cat.

Workplace specific antigens

- Wheat
- Rye
- Barley
- Soybean
- Maize
- Oat
- Buckwheat
- Egg
- Aspergillus
- Baker's yeast

Positive Control- Histamine dihydrogen chloride

Negative control- 1% Glycerinated saline solution

B) Exposure questionnaire for the cross-sectional study of bakers.



Division of Preventive Medicine

Department of Medicine

Faculty of Medicine and Dentistry

Please write patient ID number or attach sticker here.

Name of Interviewer: _____

PLACE OF INTERVIEW: _____

DATE OF INTERVIEW: _____

TIME INTERVIEW STARTED: _____

TIME INTERVIEW ENDED: _____

☐ Cohort

Height (cm): _____

☐ Cross-sectional

Weight (kg): _____

Date: _____

ID number: Please write patient ID number or
attach sticker here

Section 1 - Personal Details

1. Can I please confirm your personal details?

1.1 How old are you now? _____ Date of Birth DD / MMM / YY

1.2 What is your gender? ☐ M ☐ F

1.3 Marital status single/separated/widowed/divorced ☐ 1

married or living as married ☐ 2

Section 2 - Education

2. I would now like to ask some questions about your education.

2.1 Did you attend high school? Yes ☐ 1 No ☐ 2

If no, go to question 2.2

If yes,

2.1.1 was it in North America? Yes ☐ 1 No ☐ 2

2.1.1.1 **If yes**, what was the highest grade completed? _____

2.1.1.2 **If no**, how old were you when you left secondary education? _____

2.2 Have you ever completed an apprenticeship or formal trade training as a baker or cook?

Yes ☐ 1 No ☐ 2

3. Health

3.1 Are you in good health now?

Yes ☐ 1

No ☐ 2

If yes, go to question 3.2

If no,

3.1.1 What health problems do you have?

3.2 Are you taking any tablets or using any other medications (including inhalers) now?

Include both those prescribed by a doctor and those bought without prescription.

Yes ☐ 1

No ☐ 2

If no, go to section on the next page: **CHEST SYMPTOMS IN LAST 12 MONTHS**

If yes, please give details

What tablets or other medications are you using?	How often do you take/use it?	For what condition or symptoms are you taking this medication?
3.2.1		
3.2.2		
3.2.3		
3.2.4		

CHEST SYMPTOMS IN LAST 12 MONTHS	
1. At any time in the last 12 months have you had wheezing or whistling in your chest	No ☐ Yes ☐
2. At any time in the last 12 months have you woken up with a feeling of tightness in your chest first thing in the morning?	No ☐ Yes ☐
3. At any time in the last 12 months have you had an attack of shortness of breath that came on when you were not doing anything strenuous?	No ☐ Yes ☐
4. At any time in the last 12 months have you been woken at night by an attack of shortness of breath?	No ☐ Yes ☐
5. Have you been woken by an attack of coughing at any time in the last 12 months	No ☐ Yes ☐
If you answered NO to questions 1-5 please go to section on ASTHMA	
6. Thinking about your chest symptoms as a whole in the last 12 months, what happened to them when you were away from work for a week or longer?	Improved ☐ Same ☐ Worse ☐ N/A ☐
7. Thinking about your chest symptoms as a whole in the last 12 months, what happened to them on working days compared with non-working days	Improved ☐ Same ☐ Worse ☐ N/A ☐
8. Have these symptoms been brought on by doing any particular task or activity If Yes, which tasks or activities?	No ☐ Yes ☐

Asthma	
1. Have you ever had asthma?	No ☐ Yes ☐
If NO go to section on RHINITIS	
2. Was this confirmed by a doctor?	No ☐ Yes ☐
3. How old were you when you had your first attack of asthma?	_____ years
4. Have you had an attack of asthma in the last 12 months?	No ☐ Yes ☐
5. Have you ever been told by a doctor that you have had asthma caused by or related to your work?	No ☐ Yes ☐
6. Please indicate which of these best describes your asthma:	
☐ You had childhood asthma which went away and now you are asymptomatic ☐ You had childhood asthma which went away for several years, but is now back again ☐ You had childhood asthma which you still have at this age. ☐ You have adult onset asthma ☐ Others, please specify _____	
7. Thinking about your asthma as a whole in the last 12 months, what happened to it when you were away from work for a week or longer?	Improved ☐ Same ☐ Worse ☐ N/A ☐
8. Thinking about your asthma as a whole in the last 12 months, what happened to it on working days compared with non-working days	Improved ☐ Same ☐ Worse ☐ N/A ☐
9. Have these symptoms been brought on by doing any particular task or activity	No ☐ Yes ☐
If Yes, which tasks or activities?	

Hay fever/Rhinitis	
1. Do you have any nasal allergies or symptoms, including hay fever?	No ☐ Yes ☐
2. Have you ever had a problem with sneezing, or a blocked nose (rhinitis) when you did not have a cold or the flu?	No ☐ Yes ☐
3. Have you had an attack of sneezing, or a or a blocked nose (rhinitis) when you did not have a cold or the flu in the last 12 months?	No ☐ Yes ☐
4. How old were you when you had your first attack of rhinitis or hay fever?	_____ years
5. Has this problem been accompanied by itchy or watery eyes	No ☐ Yes ☐
6. Have you ever been told by a doctor that you have had rhinitis caused by or related to your work?	No ☐ Yes ☐
6. Thinking about your hay fever/rhinitis as a whole in the last 12 months, what happened to it when you were away from work for a week or longer?	Improved ☐ Same ☐ Worse ☐ N/A ☐
7. Thinking about your hay fever/rhinitis as a whole in the last 12 months, what happened to it on working days compared with non-working days	Improved ☐ Same ☐ Worse ☐ N/A ☐
8. Have these symptoms been brought on by doing any particular task or activity	No ☐ Yes ☐
If Yes, which tasks or activities?	

Section 4 Smoking

4.1 Have you ever smoked at least one cigarette a day for as long as a year?

Yes ☐ 1

No ☐ 2

If no, go to question 4.5

If yes,

4.2 At what age did you start smoking at least one cigarette a day?

_____ years

4.3 Do you currently smoke at least one cigarette a day?

Yes ☐ 1

No ☐ 2

If yes, go to 4.4

_____ years

If no,

4.3.1 How old were you when you last smoked at least one cigarette a day?

4.4 How many cigarettes a day do/did you usually smoke?

_____ per day

Section 5 Occupational information

5.1 Please fill the following table regarding all your occupations, starting with your current job or training position and working backwards in time.

No	Occupation	Industry	Start date (Month/Year)	End date (Month/Year)
1.				
2.				
3.				
4.				
5.				
6				

When did you first start working with flour/bakery ingredients? MMM/YY _____

5.2 Are you currently working with flour/bakery ingredients? Yes ☐ No ☐

If No, a. What date did you stop? _____

b. Why did you stop? _____

For each of the jobs above please complete the supplementary exposure questionnaire.

5.3 Before you started college or work in the jobs listed Yes ☐ No ☐

above did you regularly (once a week or more) take part in baking or other activities using flour?

If yes,

5.3.1 What did you do (please describe)?

5.3.2 In what years did you do this? Started _____ Stopped _____

5.3.4 For how many hours per week did you do this _____ hours

Section 6 Family History

1. Indicate any of the blood relatives that have had any of the following:

	Parents	Grand parents	Brother/Sister	Children
Hay fever/ Allergic Rhinitis				
Eczema (Skin Allergies)				
Asthma				
Itchy or watery eyes (Allergic Conjunctivitis)				
Other Allergies				

2. Please list any additional allergies that you yourself may have:

Please write patient ID number or attach sticker here.

Supplementary exposure questionnaire

Section 7 - supplementary exposure questionnaire.

Job number ____

7.1 What is/was your job title: _____

7.2 What type of work do you do? Please describe the tasks you carry out/carried out on a usual day.

7.3.1 Duration of work per week under the same job title:

- ☐ Less than 10 h/week ☐ 10 to <20 h/week ☐ 20 to <30 h/week
☐ 30 to 40 h/week ☐ more than 40 h/week

7.3.2 On average, how many days a week do/did you work in this job? *

- ☐ 1 day/week ☐ 2 days/week ☐ 3 days/week ☐ 4 days/week
☐ 5 days/week ☐ 6 days/week ☐ 7 days/week

If this involved working in a bakery or other workplace producing bread or other baked goods, complete questions 7.4-7.6

7.4 Were you a worker/trainee producing bread or other baked goods?

- ☐ Yes ☐ No

If yes:

What were your main products?

- ☐ Bread or bread products ☐ Confectionery/cakes ☐ Mixed

7.5 Which of these tasks best describe the work you were involved with in this job **on your last (most recent) day at work**? Choose any that apply.

- ☐ Baking/Oven Work
- ☐ Confectionary/Cake Making
- ☐ Weighing and Mixing
- ☐ Dough Forming
- ☐ All of the above production tasks
- ☐ Packing/Shipping
- ☐ Front Counter/Sales

- ☐ Cleaning/Maintenance
- ☐ Other tasks (please specify): _____

For each task selected, complete the table on pages 13-15.

For each task indicated on the previous page, describe what products are/were you making, how much of your time at work you spend/spent doing these tasks, and your use of personal protective equipment?

Type of work undertaken (Production)	Product(s)	Approximate number of hours per work day doing this task	Use of mask or respirator	Other protective equipment
Baking/oven work	Bread ☐		Simple particulate (e.g. N95) ☐	Gloves ☐
Yes ☐			Half face with filters ☐	
No ☐	Non bread/Confectionary ☐		PAPR/supplied air ☐	Earplugs ☐
			Other ☐	

	Mixed ☐		Please specify (_____)	Local exhaust ventilation/ extraction ☐
Confectionary/ cake making Yes ☐ No ☐	Bread ☐ Non bread/ Confectionary ☐ Mixed ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐ PAPR/supplied air ☐ Other ☐ Please specify (_____)	Gloves ☐ Earplugs ☐ Local exhaust ventilation/ Extraction ☐
Weighing and mixing Yes ☐ No ☐	Bread ☐ Non bread/ Confectionary ☐ Mixed ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐ PAPR/supplied air ☐ Other ☐ Please specify (_____)	Gloves ☐ Earplugs ☐ Local exhaust ventilation/ extraction ☐

Type of work undertaken	Products(s)	Approximate number	Use of mask or respirator	Other protective measures
(Production, cont'd)		of hours per work day doing this task		
Dough forming Yes ☐ No ☐	Bread ☐ Non bread/ Confectionary ☐ Mixed ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐ PAPR/supplied air ☐ Other ☐ Please specify ()	Gloves ☐ Earplugs ☐ Local exhaust ventilation/ extraction ☐
All of the above production tasks Yes ☐ No ☐	Bread ☐ Non bread/ Confectionary ☐ Mixed ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐ PAPR/supplied air ☐ Other ☐ Please specify ()	Gloves ☐ Earplugs ☐ Local exhaust ventilation/ extraction ☐

Type of work undertaken	Products(s)	Approximate number of hours per work day doing this task	Use of mask or respirator	Other protective measures
Packer/shipper Yes ☐ No ☐	Bread ☐ Non bread/ Confectionary ☐ Mixed ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐ PAPR/supplied air ☐ Other ☐ Please specify ()	Gloves ☐ Earplugs ☐ Local exhaust ventilation/ Extraction ☐
Front counter/sales Yes ☐ No ☐	Bread ☐ Non bread/ Confectionary ☐ Mixed ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐ PAPR/supplied air ☐ Other ☐ Please specify ()	Gloves ☐ Earplugs ☐ Local exhaust ventilation/ extraction ☐
Cleaner/maintenance Yes ☐	Bread ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐	Gloves ☐

No ☐	Non bread/ Confectionary ☐ Mixed ☐		PAPR/supplied air ☐ Other ☐ Please specify (_____)	Earplugs ☐ Local exhaust ventilation/ Extraction ☐
Other tasks (please specify) _____ Yes ☐ No ☐	Bread ☐ Non bread/ Confectionary ☐ Mixed ☐		Simple particulate (e.g. N95) ☐ Half face with filters ☐ PAPR/supplied air ☐ Other ☐ Please specify (_____)	Gloves ☐ Earplugs ☐ Local exhaust ventilation/ extraction ☐

7.6 Does/did this job involve work in the food processing industry?

Yes ☐

No ☐

(must be completed for current job)

7.6.1 If yes, which of the following ingredients did you work with?

Flour

Yes ☐

No ☐

Types of flour used:

Wheat ☐	Rye ☐	Barley ☐	Triticale ☐
Millet ☐	Maize ☐	Soya ☐	Other ☐ (please specify) _____

Flour improvers

Yes ☐

No ☐

Yeast

Yes ☐

No ☐

Spices and herbs

Yes ☐

No ☐

(please specify _____)

Flavourings other than spices and herbs

Yes ☐

No ☐

(please specify _____)

Colouring agents

Yes ☐

No ☐

(please specify _____)

Resins or gums

Yes ☐

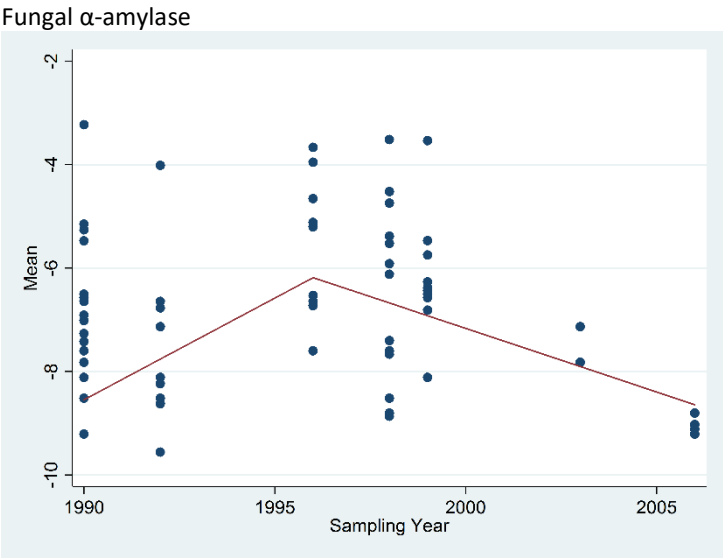
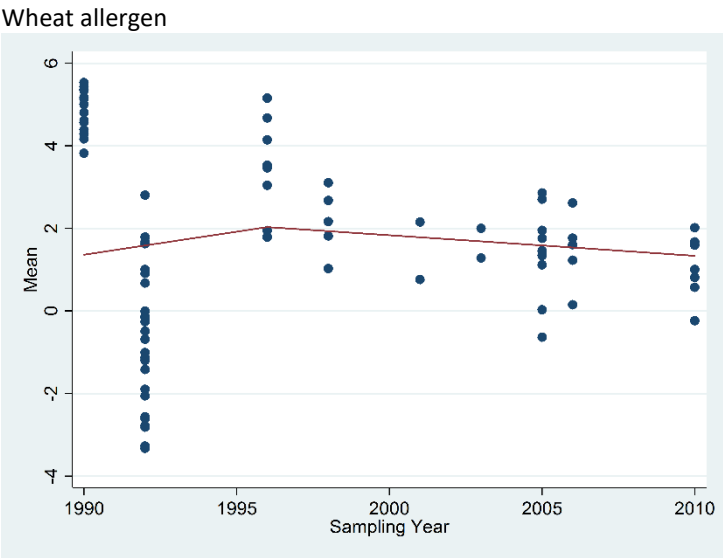
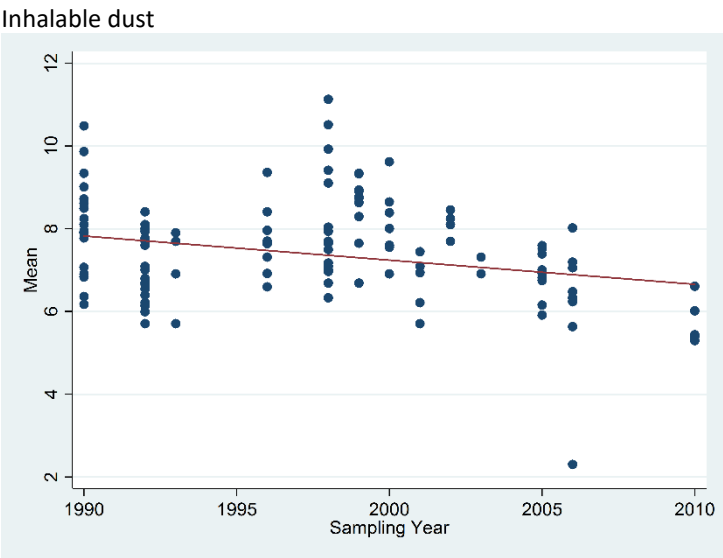
No ☐

(please specify _____)

Supplementary materials 3: Annotated Reference List	ID	WA	AA
Baatjies R, Meijster T, Heederik D, Sander I, Jeebhay MF. (2014) Effectiveness of interventions to reduce flour dust exposures in supermarket bakeries in South Africa. <i>Occupational and Environmental Medicine</i> ; 71: 811-8.	X	X	
Baatjies R, Meijster T, Lopata A, Sander I, Raulf-Heimsoth M, Heederik D, Jeebhay M. (2010) Exposure to flour dust in South African supermarket bakeries: modeling of baseline measurements of an intervention study. <i>Ann Occup Hyg</i> ; 54: 309-18.	X	X	X
Brant A, Berriman J, Sharp C, Welch J, Zekveld C, Nieuwenhuijsen M, Elms J, Newman-Taylor A, Cullinan P. (2005) The changing distribution of occupational asthma: a survey of supermarket bakery workers. <i>Eur Respir J</i> ; 25: 303-8.	X		
Brisman J, Toren K, Lillienberg L, Karlsson G, Ahlstedt S. (1998) Nasal symptoms and indices of nasal inflammation in flour-dust-exposed bakers. <i>Int Arch Occup Environ Health</i> ; 71: 525-32.	X		
Bulat P, Myny K, Braeckman L, van Sprundel M, Kusters E, Doekes G, Possel K, Droste J, Vanhoorne M. (2004) Exposure to inhalable dust, wheat flour and alpha-amylase allergens in industrial and traditional bakeries. <i>Ann Occup Hyg</i> ; 48: 57-63.	X	X	X
Burdorf A, Lillienberg L, Brisman J. (1994) Characterization of exposure to inhalable flour dust in Swedish bakeries. <i>Ann Occup Hyg</i> ; 38: 67-78.	X		
Burstyn I, Teschke K, Bartlett K, Kennedy SM. (1998) Determinants of wheat antigen and fungal alpha-amylase exposure in bakeries. <i>American Industrial Hygiene Association Journal</i> ; 59: 313-20.		X	X
Burstyn I, Teschke K, Kennedy SM. (1997) Exposure levels and determinants of inhalable dust exposure in bakeries. <i>Ann Occup Hyg</i> ; 41: 609-24.	X		
Elms J, Beckett P, Griffin P, Evans P, Sams C, Roff M, Curran AD. (2003) Job categories and their effect on exposure to fungal alpha-amylase and inhalable dust in the U.K. baking industry. <i>AIHA J (Fairfax, Va)</i> ; 64: 467-71.	X		X
Elms J, Denniss S, Smith M, Evans PG, Wiley K, Griffin P, Curran AD. (2001) Development and validation of a monoclonal based immunoassay for the measurement of fungal alpha-amylase: focus on peak exposures. <i>Ann Occup Hyg</i> ; 45: 89-95.	X		X
Elms J, Robinson E, Rahman S, Garrod A. (2005) Exposure to flour dust in UK bakeries: current use of control measures. <i>Ann Occup Hyg</i> ; 49: 85-91.	X		
Houba R, Heederik D, Doekes G. (1998) Wheat sensitization and work-related symptoms in the baking industry are preventable. An epidemiologic study. <i>Am J Respir Crit Care Med</i> ; 158: 1499-503.	X		
Houba R, Heederik D, Kromhout H. (1997) Grouping strategies for exposure to inhalable dust, wheat allergens and alpha-amylase allergens in bakeries. <i>Ann Occup Hyg</i> ; 41: 287-96.	X	X	
Houba R, van Run P, Doekes G, Heederik D, Spithoven J. (1997) Airborne levels of alpha-amylase allergens in bakeries. <i>J Allergy Clin Immunol</i> ; 99: 286-92.	X	X	
Houba R, Van Run P, Heederik D, Doekes G. (1996) Wheat antigen exposure assessment for epidemiological studies in bakeries using personal dust sampling and inhibition ELISA. <i>Clin Exp Allergy</i> ; 26: 154-63.			X
Hur GY, Koh DH, Kim HA, Park HJ, Ye YM, Kim KS, Park HS. (2008) Prevalence of work-related symptoms and serum-specific antibodies to wheat flour in exposed workers in the bakery industry. <i>Respir Med</i> ; 102: 548-55.	X		
Jeffrey P, Griffin P, Gibson M, Curran AD. (1999) Small bakeries--a cross-sectional study of respiratory symptoms, sensitization and dust exposure. <i>Occup Med (Lond)</i> ; 49: 237-41.	X		
Lillienberg L, Baur X, Doekes G, Belin L, Raulf-Heimsoth M, Sander I, Stahl A, Thissen J, Heederik D. (2000) Comparison of four methods to assess fungal alpha-amylase in flour dust. <i>Ann Occup Hyg</i> ; 44: 427-33.			X
Lillienberg L, Brisman J. (1994) Flour Dust in Bakeries - a Comparison between Methods. <i>Inhaled Particles VII</i> ; 571-75.	X		
Meijster T, Tielemans E, de Pater N, Heederik D. (2007) Modelling exposure in flour processing sectors in the Netherlands: a baseline measurement in the context of an intervention program. <i>Ann Occup Hyg</i> ; 51: 293-304.	X	X	X
Nieuwenhuijsen MJ, Heederik D, Doekes G, Venables KM, Newman Taylor AJ. (1999) Exposure-response relations of alpha-amylase sensitisation in			X

British bakeries and flour mills. Occupational and Environmental Medicine; 56: 197-201.			
Nieuwenhuijsen MJ, Sandiford CP, Lowson D, Tee RD, Venables KM, McDonald JC, Newman Taylor AJ. (1994) Dust and flour aeroallergen exposure in flour mills and bakeries. Occupational and Environmental Medicine; 51: 584-8.		X	
Peretz C, de Pater N, de Monchy J, Oostenbrink J, Heederik D. (2005) Assessment of exposure to wheat flour and the shape of its relationship with specific sensitization. Scand J Work Environ Health; 31: 65-74.	X	X	
Smith TA. (2004) Preventing baker's asthma: an alternative strategy. Occup Med (Lond); 54: 21-7.	X		
Smith TA, Smith PW. (1998) Respiratory symptoms and sensitization in bread and cake bakers. Occup Med (Lond); 48: 321-8.	X		
Stuurman B, Meijster T, Heederik D, Doekes G. (2008) Inhalable beta(1->3)glucans as a non-allergenic exposure factor in Dutch bakeries. Occupational and Environmental Medicine; 65: 68-70.	X	X	
Vanhanen M, Tuomi T, Hokkanen H, Tupasela O, Tuomainen A, Holmberg PC, Leisola M, Nordman H. (1996) Enzyme exposure and enzyme sensitisation in the baking industry. Occupational and Environmental Medicine; 53: 670-6.			X

Supplementary materials 4: Plot of log transformed geometric means against year of sampling for inhalable dust, wheat allergen and fungal α -amylase ($\mu\text{g}/\text{m}^3$)



Supplementary materials 5: Inhalable dust: univariate and multivariable models including AL exposure data with data from the literature

	Univariate			Multivariable		
	β	SE	CI (95%)	β	SE	CI (95%)
Task						
Oven tasks	1.54	0.15	1.24 - 1.84	1.42	0.17	1.08 - 1.76
Confectionary tasks	0.97	0.26	0.46 - 1.48	0.87	0.29	0.30 - 1.43
Weighing/Mixing	1.98	0.20	1.59 - 2.36	1.97	0.19	1.59 - 2.35
Dough former	1.36	0.21	0.94 - 1.78	1.34	0.21	0.93 - 1.75
Other production	0.54	0.13	0.29 - 0.80	0.55	0.13	0.29 - 0.81
Carried out all tasks	1.10	0.30	0.51 - 1.68	1.04	0.28	0.49 - 1.59
Non-Production	rc	rc	rc	rc	rc	rc
Bakery Size						
Small	0.60	0.09	0.42 - 0.78	0.26	0.09	0.08 - 0.44
Medium	-0.07	0.27	-0.60 - 0.46	-0.09	0.37	-0.83 - 0.64
Multiple	0.13	0.12	-0.11 - 0.38	-0.18	0.13	-0.43 - 0.07
Large	rc	rc	rc	rc	rc	rc
Product						
Bread	0.35	0.32	-0.29 - 0.98			
Confectionary	0.02	0.29	-0.54 - 0.58			
Mixed	rc	rc	rc			
Filter						
Cellulose/Other	0.53	0.32	-0.11 - 1.16			
Glass Fiber	0.95	0.37	0.22 - 1.68			
Teflon	rc	rc	rc			
Sampling Head						
7-hole	1.19	0.22	0.76 - 1.61	0.63	0.19	0.27 - 0.99
IOM	0.66	0.33	0.02 - 1.30	0.51	0.34	-0.15 - 1.18
PAS6	rc	rc	rc	rc	rc	rc
Place						
United-Kingdom	0.73	0.37	-0.00 - 1.47			
North-America	0.52	0.18	0.17 - 0.86			
South-Africa/Europe	rc	rc	rc			
Years Since 1990	-0.05	0.02	-0.09 - -0.01	-0.04	0.01	-0.06 - -0.02
Years Since 1996	-0.07	0.03	-0.13 - -0.00			
Alberta	0.07	0.16	-0.25 - 0.39			
Constant	7.38*	0.17	7.05 - 7.70	6.32	0.09	6.14 - 6.51

rc Denotes the reference category

*model with intercept only

Univariate model with intercept only: variance within studies=0.49; between studies=0.58

Multivariable model: variance within studies= 0.16; between studies=0.37