

Exposure to Inhalable Dust, Wheat Flour and α -Amylase Allergens in Industrial and Traditional Bakeries

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This study was designed to characterize exposure to inhalable dust, wheat flour and α -amylase allergens in industrial and traditional bakeries. The study included 70 bakeries from the northern part of Belgium. Based on the degree of automation and a clear division of individual job tasks, four bakeries were identified as industrial and the remaining 66 were identified as traditional ones. Personal, as well as stationary, samples of inhalable dust were collected during full shift periods, usually 5–7 h. The portable pumps aspirated 2 l/min through Teflon personal dust samplers (Millipore, pore size 1.0 μ m) mounted in PAS-6 sampling heads. In the collected samples the inhalable dust, wheat flour and α -amylase allergens were determined. Wheat flour allergens were measured using enzyme-linked immunosorbent assay inhibition and an anti-wheat IgG4 serum pool. The α -amylase allergens were measured using a sandwich enzyme immunoassay with affinity-purified polyclonal rabbit IgG antibodies. In total, 440 samples (300 personal and 140 stationary) were processed. The highest inhalable dust exposure was observed in traditional bakeries among bread [geometric mean (GM) 2.10 mg/m³] and bread and pastry workers (GM 1.80 mg/m³). In industrial bakeries the highest dust exposure was measured in bread-producing workers (GM 1.06 mg/m³). Similar relations were observed for wheat flour and α -amylase allergens. Bread baking workers in traditional bakeries had the highest exposure to both allergens (wheat flour GM 22.33 μ g/m³, α -amylase GM 0.61 ng/m³). The exposure to wheat flour and α -amylase allergens in industrial bakeries was higher in bread baking workers (wheat flour GM 6.15 μ g/m³, α -amylase GM 0.47 ng/m³) than in bread packing workers (wheat flour GM 2.79 μ g/m³, α -amylase GM 0.15 ng/m³). The data presented suggest that, on average, exposure in the Belgium bakeries studied—industrial as well as traditional—is lower than or similar to bakeries in The Netherlands, Canada, Sweden, the United Kingdom and Finland. Furthermore, the exposure levels in traditional bakeries seem to be higher than in industrial bakeries.

Keywords: α -amylase; bakeries; inhalable dust; occupational exposure; wheat flour

INTRODUCTION

Although respiratory problems in bakers were already recognized in Roman slaves, and bakers'

asthma was described by Bernardino Ramazzini, prevention has obviously not been very successful hitherto as the disease is still frequent in bakers. In several countries bakers' asthma is the most frequent occupational asthma (Toren, 1996; Bena *et al.*, 1999; Karjalainen *et al.*, 2000). The incidence of bakers' asthma varies from 4% up to 10% in different reports (Jarvinen *et al.*, 1979; Thiel and Ulmer, 1980; Zuskin

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et al., 1994; De Zotti and Bovenzi, 2000). The estimated annual incidence of bakers' asthma in the United Kingdom varies from 409 in 1989 (Meredith *et al.*, 1991) up to 951 per million (McDonald *et al.*, 2000). Brisman *et al.* (2000) reported that the incidence of asthma among Swedish bakers with the highest exposure to dust was 7.3 and 6.5/1000 person years in men and women, respectively. During the period from 1963 to 1999, the Belgian Fund of Occupational Diseases recognized 1065 cases of occupational asthma among workers employed in bakeries (Anonymous, 1999). However, there is certainly more occupational asthma in this setting since this number does not include the cases of asthma among self-employed bakers in Belgium. The reported prevalence of work-related chest symptoms in bakers is in the range 5–13% (Prichard *et al.*, 1984; Rosenberg *et al.*, 1991; Vanhanen *et al.*, 1996; Houba *et al.*, 1998).

In the last 20 yr wheat flour (*Triticum aestivum*) and other cereal flours (*Secale cereale*, *Hordeum vulgare*) have often been reported as principal allergens for bakers' allergy and asthma (Prichard *et al.*, 1984; Matsumura *et al.*, 1994; Sanchez-Monge *et al.*, 1997; Baur *et al.*, 1998; Pavlovic *et al.*, 2001).

Moreover, from the 1970s onwards, bakers started using enzymes for bread improvement, which later appeared to be potent allergens. Various authors (Vanhanen *et al.*, 1996; Smith and Smith, 1998) reported that α -amylase allergens are the main cause of bakers' allergy and asthma (Vanhanen *et al.*, 1996; Smith and Smith, 1998; Jeffrey *et al.*, 1999).

In the last 20 yr most exposure assessments have been performed in industrial bakeries (Nieuwenhuijsen, 1994, 1995b; Houba *et al.*, 1996; Vanhanen *et al.*, 1996; Burstyn *et al.*, 1997; Cullinan *et al.*, 2001). Industrial bakeries are probably better monitored by occupational health services and authorities. In a number of countries, however, as in Belgium, there are few industrial bakeries and most bread is produced in traditional bakeries. These traditional bakeries usually have few (1–5) workers and a self-employed owner. It is estimated that traditional bakeries in Belgium employ >15200 workers (Anonymous, 1996). Usually, technology in traditional bakeries is not as developed as in industrial bakeries, and often a lot of the work is manual. Contrary to the industrial bakeries, traditional bakeries are rarely visited by health and safety experts and there is little literature dealing with exposure assessment in these bakeries. Most papers dealing with small and medium-sized bakeries differentiate these by the number of employees (Burdorf *et al.*, 1994; Houba *et al.*, 1996; Burstyn *et al.*, 1998; Jeffrey *et al.*, 1999). Jeffrey *et al.* (1999) consider bakeries with <50 workers as small bakeries, whereas Burdorf *et al.* (1994) use the term small bakery for bakeries with <10 workers. Houba *et al.* (1996) consider that small

bakeries engage 1–6 workers. This approach is not always applicable, especially nowadays, when technological development and automation is taking place. It is important to notice that Houba *et al.* (1996) also took the level of automation into consideration, but they did not mention criteria for that. In that paper (Houba *et al.*, 1996), the authors used at some points the term traditional bakery for a small bakery. So, it is not always clear which of the above-mentioned papers deal with traditional bakeries and which with small industrial bakeries.

This study was designed to characterize and compare exposure to inhalable dust, wheat flour and α -amylase allergens in industrial and traditional bakeries.

MATERIALS AND METHODS

The study included 70 bakeries from 4 (of the 10) provinces of Belgium (53 from Antwerp, 15 from East Flanders, 1 from Brabant and 1 from Limburg), which agreed to participate and in which owners as well as workers gave written informed consent. All bakeries (response rate 36%) who agreed to participate in the study were visited by the fieldworkers. Based on the degree of automation and a clear division of individual job tasks, four bakeries were identified as industrial bakeries. In the remaining 66, the job tasks were not clearly divided and the level of automation was poor, so they were identified as traditional bakeries. Among these four industrial bakeries, one produced bread and pastry, all others produced bread only. The limited number of persons involved in pastry production in industrial bakeries and technical problems with five samples from that department caused exclusion of their exposure assessment data from our analyses. Due to the limited number of workers involved in three tasks—sandwich production, warehouse and technical staff—their exposure data were also excluded from this paper. In industrial bakeries it was possible to identify two different job tasks—baker and packing worker—that were common to all four bakeries. Data on the number of workers involved in personal monitoring according to type of bakery and job tasks are presented in Table 1.

In traditional bakeries there was no clear division between bread and pastry production. In fact, almost all traditional bakeries produced both bread and pastry. Often, in traditional bakeries, bread and pastry production took place in the same room, one worker fulfilling several job tasks. Nevertheless it was possible to divide them into three categories: bread, pastry, and bread and pastry producing workers (Table 1).

Since the job tasks and work performed in each bakery, especially in traditional bakeries, were significantly different, within each bakery samples were taken from more than one baker.

Table 1. Number of workers involved in personal monitoring according to type of bakery and job tasks

Bakery type	Bread production	Pastry production	Bread and pastry production	Packing	Sandwich production	Warehouse worker	Technical staff
Industrial	36	13	—	34	5	3	3
Traditional	23	37	84	—	—	—	—

Measurement of inhalable dust, wheat flour and α -amylase allergens exposure

During personal monitoring, stationary monitoring was performed concurrently in all traditional bakeries as well. In all traditional bakeries at least two stationary samples were taken: one at the working table and a second one at the dough-making area. The samples were collected between 2 December 1996 and 27 January 1999.

Personal, as well as stationary, samples of inhalable dust were collected during full shift periods, usually 5–7 h. The workers wore on their belt portable pumps (Gillair 5) which aspirated 2 l/min through Teflon filters (Millipore, pore size 1.0 μ m) mounted in PAS-6 sampling heads on their lapels (Kuile, 1984). The same equipment was used for stationary measurement. After sampling, the filters were transported to the Department of Environmental Sciences at Wageningen University, The Netherlands. In this laboratory the filters were weighed according to a previously published methodology (Houba *et al.*, 1996). The detection limit of this method is 0.17 mg. The wheat flour and α -amylase allergens were recovered from the filters by extraction with 2.5 ml 0.15 M phosphate-buffered saline (PBS, pH 7.4). Wheat flour allergens were measured using enzyme-linked immunosorbent assay inhibition and an antiwheat IgG4 serum pool (Houba *et al.*, 1996). All samples were analyzed in duplicate on two different days and the mean value was used for further statistical analysis. The detection limit of this method is 50 ng/ml. The α -amylase allergens were measured using a sandwich enzyme immunoassay with affinity-purified polyclonal rabbit IgG antibodies (Houba *et al.*, 1997b). The detection limit of this method is 100 pg/ml.

For data analysis, the measurements below detection limits were replaced by the values of the analytical limit of detection divided by the square root of 2 (Hornung and Reed, 1990) and then divided by the volume of air drawn through the sample.

Data analysis

All statistical analyses were performed using SPSS software (v. 10.1). The geometric standard deviation (GSD) was calculated by exponentiation of the standard deviation (SD) of the log-transformed exposure data. The distributions of exposure data were examined upon normality by visualization of normal probability plots. Since the distribution of all

exposure variables differed significantly from the normal distribution, the following descriptive measures of exposure are presented: the geometric mean (GM), GSD, the median, the 25th and 75th percentile, minimum and maximum.

Since the exposure data, especially the α -amylase allergens data, had a substantial number of values below the detection limits, and since log normal transformation of data did not improve normality of distribution, data were compared using the Kruskal–Wallis test. The associations between the exposure levels and type of bakery were assessed using Spearman's rank correlation coefficients.

The data on sampling time and volume are presented with the following descriptive parameters: arithmetic mean (AM), SD, minimum and maximum.

RESULTS

Out of 440 samples (300 personal and 140 stationary) processed, 29 were discarded (24 personal and 5 stationary) due to various technical problems. Most of the discarded personal samples originated from one industrial bakery (14 out of 26 discarded personal samples). The average sampling time for personal monitoring was 322 ± 88 and 348 ± 83 min (AM $\pm$ SD) for stationary monitoring. The average volume aspirated during personal monitoring was 0.64 ± 0.17 and 0.69 ± 0.16 m³ (AM $\pm$ SD) in stationary sampling.

The inhalable dust exposure data are presented in Table 2. The GMs of the personal monitoring inhalable dust showed a statistically significant difference among examined groups ($P < 0.001$). The highest inhalable dust exposures were observed in traditional bakeries among bread and bread and pastry workers. These exposures were significantly higher than those in industrial bakeries among packaging workers and in traditional bakery pastry workers ($P < 0.001$). For the stationary inhalable dust measurements in traditional bakeries, the GMs were similar in both monitored areas, dough making and worktable.

The exposure to wheat flour allergens is summarized in Table 3. The wheat flour allergen exposures differ significantly among the groups examined ($P < 0.001$). The highest exposure levels were found among traditional bakeries in bread production and bread and pastry workers. The personal wheat flour allergen exposures of these two groups were significantly higher than in the other three groups ($P <$

Table 2. Inhalable dust exposure (mg/m³)

Type of monitoring	Type of bakery	Job task	<i>n</i>	%<dl	GM	GSD	Median	P ₂₅	P ₇₅	Min.	Max.
Personal monitoring	Industrial	Baker	22	18.2	1.06	3.61	1.39	0.35	2.74	0.17	8.52
		Packaging	31	6.1	0.56	2.09	0.49	0.34	0.76	0.22	2.17
	Traditional	Bread production	29	0	2.10	2.42	1.83	1.32	3.55	0.30	13.30
		Pastry production	57	14.0	1.11	2.55	1.34	0.57	1.76	0.23	8.70
		Bread and pastry production	135	3.0	1.80	2.30	1.89	1.02	3.03	0.17	13.37
Stationary measurement	Traditional	Dough making	77	1.3	1.55	2.15	1.55	0.95	2.79	0.14	8.96
		Worktable	59	1.7	1.42	2.33	1.53	0.72	2.53	0.15	6.64

%<dl, percentage of samples below the detection limits; GM, geometric mean; GSD, geometric standard deviation; P₂₅, 25th percentile; P₇₅, 75th percentile.

Table 3. Wheat flour allergen exposure (µg/m³)

Type of monitoring	Type of bakery	Job task	<i>n</i>	%<dl	GM	GSD	Median	P ₂₅	P ₇₅	Min.	Max.
Personal monitoring	Industrial	Baker	20	0	6.15	3.57	5.24	2.18	14.23	1.46	100.29
		Packaging	32	2.9	2.79	2.25	2.43	1.54	4.32	0.46	48.44
	Traditional	Bread production	30	0	22.33	2.97	22.89	9.09	47.06	1.99	171.23
		Pastry production	60	3.3	8.71	4.16	9.75	2.66	27.29	0.58	150.72
		Bread and pastry production	138	2.2	14.48	3.75	18.34	4.88	34.13	0.46	205.96
Stationary measurement	Traditional	Dough making	78	0	14.76	3.47	19.17	8.99	37.72	0.73	98.67
		Worktable	60	6.4	13.91	5.16	19.94	6.31	46.01	0.43	179.35

%<dl, percentage of samples below the detection limits; GM, geometric mean; GSD, geometric standard deviation; P₂₅, 25th percentile; P₇₅, 75th percentile.

Table 4. α-Amylase allergen exposure (ng/m³)

Type of monitoring	Type of bakery	Job task	<i>n</i>	%<dl	GM	GSD	Median	P ₂₅	P ₇₅	Min.	Max.
Personal monitoring	Industrial	Baker	22	63.6	0.47	7.19	0.19	0.11	1.27	0.11	136.16
		Packaging	32	85.3	0.15	1.74	0.12	0.11	0.15	0.11	1.24
	Traditional	Bread production	29	40.0	0.61	3.89	0.40	0.20	1.82	0.11	17.65
		Pastry production	59	55.9	0.47	4.04	0.28	0.17	1.23	0.10	51.13
		Bread and pastry production	130	43.8	0.50	4.47	0.29	0.13	1.44	0.10	37.46
Stationary measurement	Traditional	Dough making	71	50.7	0.33	3.37	0.22	0.12	0.78	0.10	7.29
		Worktable	55	54.5	0.34	3.58	0.21	0.12	0.79	0.10	6.08

%<dl, percentage of samples below the detection limits; GM, geometric mean; GSD, geometric standard deviation; P₂₅, 25th percentile; P₇₅, 75th percentile.

0.01). Also, the wheat flour allergen exposures were significantly higher in industrial bakeries among bread-producing workers in comparison with packaging workers ($P < 0.01$). The stationary data show that wheat flour allergen exposure levels in traditional bakeries were similar in both monitored areas (Table 3).

The data on α-amylase allergen exposure are presented in Table 4. The personal monitoring data on α-amylase allergen exposure in bakeries showed

statistically significant differences among examined groups ($P < 0.001$). Again, the traditional bakery bread production workers had the highest exposure. The α-amylase allergen exposure was significantly lower in industrial bakery packaging workers than in all other groups ($P < 0.01$). The majority of α-amylase allergen exposure data for packaging workers in industrial bakeries were below the detection limit. The range of exposure data is also narrow, suggesting that this group had only limited exposure

Table 5. Correlations between inhalable dust, wheat flour and α -amylase allergens in different types of bakeries

		Total dust- wheat	Total dust- α -amylase	Wheat- α - amylase
Industrial	Baker	0.125	0.450*	0.104
	Packaging	0.279	0.373*	0.411*
Traditional	Bread production	0.628**	0.551**	0.459*
	Pastry production	0.521**	0.200	0.162
	Bread and pastry production	0.493**	0.501**	0.194*

* $P < 0.05$; ** $P < 0.01$.

to α -amylase allergens. The stationary measurement data in dough making and worktable areas of traditional bakeries suggest that α -amylase allergen exposure is similar in these areas.

In traditional bakeries, total dust measurements significantly correlate with wheat flour and α -amylase allergens. Table 5 presents the correlation between the exposure to inhalable dust, wheat flour and α -amylase allergens and type of bakery.

DISCUSSION

Exposure assessment is one of the most important parts of every epidemiological study. This is the reason why in the Flemish bakers' allergy study considerable attention was paid to the determination of wheat flour and α -amylase allergens as well as to other factors that could modify the exposure.

As already mentioned, there are many misunderstandings over the term 'small' bakery. The term 'traditional bakery' seems better than small bakery, because it takes into account the level of industrialization rather than the number of employees. This is very important, because the level of exposure to dust and allergens is more closely associated with the technological level than the number of employees. In this study the classification criteria were level of industrialization and clear division of individual job tasks. The bakeries using traditional technology were considered as traditional (non-industrial) bakeries. As almost all traditional bakeries produce bread as well as pastry, and as the number of employees is limited, workers are frequently involved in both activities. Most participants (84) in our study dealt with bread and pastry production. In traditional bakeries, the persons involved in pastry production only very often had similar exposure levels as bread-producing workers due to the proximity of their workplaces.

As this study involved a number of traditional bakeries (66), and as each of them had a different organization of working hours and production, the average sampling time and volume was less than in

industrial bakeries except for the traditional bakeries producing bread and pastry. In this case, the workers continued to work on pastry production after working on bread production; therefore the sampling time and volume were in the same range as that of industrial bakeries.

In industrial bakeries, the inhalable dust, wheat flour and α -amylase allergen exposure of bread-producing workers in this study were in general lower than in other studies (Nieuwenhuijsen *et al.*, 1994, 1995a; Houba *et al.*, 1996; Vanhanen *et al.*, 1996). In fact, bearing in mind that in the present study some individual job tasks in the bread-producing process were aggregated, due to limited number of individuals, the results probably correspond to the group of 'all-round staff' proposed by Dutch researchers (Houba *et al.*, 1997a). The inhalable dust exposure was within the range of a British study (Nieuwenhuijsen *et al.*, 1994, 1995a), whereas the α -amylase exposure was lower than in British and Dutch studies although it was still comparable (Houba *et al.*, 1997b; Nieuwenhuijsen *et al.*, 1999). On the contrary, the α -amylase results are not at all in agreement with Finnish data that are ~500-fold higher (Vanhanen *et al.*, 1996). The huge discrepancy between the Finnish data and the findings in other countries could be explained by differences in the laboratory methodology (non-selective method for α -amylase) and the standards used in the Finnish study (M. Vanhanen, personal communication).

The exposure to inhalable dust and α -amylase allergens of workers involved in packing is almost the same as in the Dutch study (Houba *et al.*, 1996, 1997a; Nieuwenhuijsen *et al.*, 1994, 1995a). Although the presence of α -amylase is not expected in the packing area, the previous and current results suggest that some contamination in that area cannot be avoided. The wheat flour allergen exposures were lower than in the Dutch study (Houba *et al.*, 1996, 1997a). As expected, the inhalable dust, wheat flour and α -amylase allergens exposure in industrial bakeries were significantly lower in packing workers than in bread-baking workers.

There are only few studies on exposure assessment in traditional bakeries. The inhalable dust exposure in traditional bakeries in our study corresponds with results of Canadian, Dutch and Swedish studies (Burdorf *et al.*, 1994; Houba *et al.*, 1996; Burstyn *et al.*, 1997); however, it is significantly lower than in the Scottish study (Jeffrey *et al.*, 1999). The comparison of wheat flour allergen exposure in traditional bakeries in Belgium, The Netherlands and Canada suggests that the exposure in the Belgian study is lower than in the Dutch and comparable with the Canadian study (Houba *et al.*, 1996, 1997a; Burstyn *et al.*, 1998). The α -amylase allergen exposure in traditional bakeries was in the same range as in the Dutch study except for pastry production (Houba *et*

al., 1997b). The α -amylase allergen exposure in pastry production seems to be significantly higher in our study than in the Dutch study, but it is similar to the Canadian study (Burstyn *et al.*, 1998). Unlike pastry production, the α -amylase allergens exposure in bread production workers is almost 10-fold lower than in the Canadian study. Unexpectedly, α -amylase allergen exposure does not differ significantly among groups of traditional bakeries.

The stationary measurements of inhalable dust, wheat flour and α -amylase allergens were in the expected ranges and were similar in the dough-making and the worktable areas.

The most important finding of this study is that the inhalable dust, wheat flour and α -amylase allergen exposure is higher in traditional bakeries than in industrial ones. The exposure to inhalable dust in our study is well below the occupational exposure limit currently used in Belgium (4 mg/m³) (Anonymous, 2001a). However, some of these values were more than four times higher than the time-weighted average threshold limit values (TLV-TWA) recently proposed by the American Conference of Governmental Industrial Hygienists (0.5 mg/m³) (Anonymous, 2001b).

There are several limitations to the present study. The results may be biased by the low participation rate of bakeries; in our view, this was especially the case among traditional bakeries. Bakeries with high exposures might have been less inclined to participate in the study, thus leading to an underestimate of exposure. The categorizing of traditional versus industrial bakeries was based on the investigators' judgement. Therefore, results may be difficult to compare with other studies. The exposure in some job tasks could not be properly evaluated due to the small number of samples. Therefore, further studies with a larger number of (repeated) measurements are recommended to address the problem of within- and between-worker variability.

Finally, due to limited means, the study was confined to a part of Belgium. One should be cautious in extrapolating these results to the whole of Flanders, let alone Belgium.

Presented data suggest that, on average, exposure in the Belgium bakeries studied—industrial as well as traditional—is lower or in agreement with bakeries in The Netherlands, Canada, Sweden, the United Kingdom and Finland. Also, the exposure to inhalable dust as well as allergens in traditional bakeries seems to be higher than in industrial ones. Having in mind that traditional bakeries are not regularly monitored and that this sector employs a significant number of people, further studies on ways to reduce exposure to allergens in traditional bakeries are recommended. Moreover, the owners of traditional bakeries are usually self-employed, and thus rarely participate in periodic occupational health examin-

ations. With the assumption that they mostly encounter the same exposure as their workers, it is quite reasonable to propose their inclusion in occupational health survey programmes.

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REFERENCES

- Anonymous. (1996) NBBF brochure. Nationale Belgische Federatie der Bakkers en Banketbakkers met personeel [Belgian National Federation of Bakers and Pastry Workers with Personnel]. St Pieters Leeuw.
- Anonymous. (1999) Jaarverslag [Annual report]. Fonds voor de Beroepsziekten [Fund for Occupational Diseases]. Brussels.
- Anonymous. (2001a) Algemeen Reglement voor de Arbeidsbescherming Bijlage II artikel 103series. [General Regulation for Labour Protection. Annex II article 103series]. Diegem: Kluwer.
- Anonymous. (2001b) Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
- Baur X, Degens PO, Sander I. (1998) Baker's asthma: still among the most frequent occupational respiratory disorders. *J Allergy Clin Immunol*; 102: 984–97.
- Bena A, D'Errico A, Mirabelli D. (1999) Un sistema di rilevazione attiva dell'asma bronchiale professionale: i risultati di due anni di attività del programma PRIOR [A system for the active surveillance of occupational bronchial asthma: the results of 2 years of activity of the PRIOR program]. *Med Lav*; 90: 556–71.
- Brisman J, Jarvholm B, Lillienberg L. (2000) Exposure-response relations for self reported asthma and rhinitis in bakers. *Occup Environ Med*; 57: 335–40.
- Burdorf A, Lillienberg L, Brisman J. (1994) Characterization of exposure to inhalable flour dust in Swedish bakeries. *Ann Occup Hyg*; 38: 67–78.
- Burstyn I, Teschke K, Kennedy SM. (1997) Exposure levels and determinants of inhalable dust exposure in bakeries. *Ann Occup Hyg*; 41: 609–24.
- Burstyn I, Teschke K, Bartlett K, Kennedy SM. (1998) Determinants of wheat antigen and fungal alpha-amylase exposure in bakeries. *Am Ind Hyg Assoc J*; 59: 313–20.
- Cullinan P, Cook A, Nieuwenhuijsen MJ, *et al.* (2001) Allergen and dust exposure as determinants of work-related symptoms and sensitization in a cohort of flour-exposed workers; a case-control analysis. *Ann Occup Hyg*; 45: 97–103.
- De Zotti R, Bovenzi M. (2000) Prospective study of work related respiratory symptoms in trainee bakers. *Occup Environ Med*; 57: 58–61.
- Hornung RW, Reed LD. (1990) Estimation of average concentrations in presence of nondetectable values. *Appl Occup Environ Hyg*; 5: 46–51.
- 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. *Clin Exp Allergy*; 26: 154–63.
- Houba R, Heederik D, Kromhout H. (1997a) Grouping strategies for exposure to inhalable dust, wheat allergens and alpha-amylase allergens in bakeries. *Ann Occup Hyg*; 41: 287–96.

- Houba R, van Run P, Doekes G, Heederik D, Spithoven J. (1997b) Airborne levels of alpha-amylase allergens in bakeries. *J Allergy Clin Immunol*; 99: 286–92.
- Houba R, Heederik D, Doekes G. (1998) Wheat sensitization and work-related symptoms in the baking industry are preventable. An epidemiologic study. *Am J Respir Crit Care Med*; 158: 1499–503.
- Jarvinen KA, Pirila V, Bjorksten F, Keskinen H, Lehtinen M, Stubb S. (1979) Unsuitability of bakery work for a person with atopy: a study of 234 bakery workers. *Ann Allergy*; 42: 192–5.
- Jeffrey P, Griffin P, Gibson M, Curran AD. (1999) Small bakeries—a cross-sectional study of respiratory symptoms, sensitization and dust exposure. *Occup Med*; 49: 237–41.
- Karjalainen A, Kurppa K, Virtanen S, Keskinen H, Nordman H. (2000) Incidence of occupational asthma by occupation and industry in Finland. *Am J Ind Med*; 37: 451–8.
- Kuile, WM ter. (1984) Vergleichmessungen mit verschiedenen Geraeten zur Bestimmung der Gesamtstaubkonzentration am Arbeitsplatz: Teil II. *Staub Reinh Luft*; 44: 211–6.
- Matsumura Y, Niitsuma T, Ito H. (1994) A study of factors contributing to bakers' allergy symptoms. *Arerugi*; 43: 625–33.
- McDonald JC, Keynes HL, Meredith SK. (2000) Reported incidence of occupational asthma in the United Kingdom, 1989–97. *Occup Environ Med*; 57: 823–9.
- Meredith SK, Taylor VM, McDonald JC. (1991) Occupational respiratory disease in the United Kingdom 1989: a report to the British Thoracic Society and the Society of Occupational Medicine by the SWORD project group. *Br J Ind Med*; 48: 292–8.
- Nieuwenhuijsen MJ, Sandiford CP, Lowson D, *et al.* (1994) Dust and flour aeroallergen exposure in flour mills and bakeries. *Occup Environ Med*; 51: 584–8.
- Nieuwenhuijsen MJ, Lowson D, Venables KM, Newman Taylor AJ. (1995a) Flour dust exposure variability in flour mills and bakeries. *Ann Occup Hyg*; 39: 299–305.
- Nieuwenhuijsen MJ, Sandiford CP, Lowson D, Tee RD, Venables KM, Newman Taylor AJ. (1995b) Peak exposure concentrations of dust and flour aeroallergen in flour mills and bakeries. *Ann Occup Hyg*; 39: 193–201.
- Nieuwenhuijsen MJ, Heederik D, Doekes G, Venables KM, Newman Taylor AJ. (1999) Exposure-response relations of alpha-amylase sensitisation in British bakeries and flour mills. *Occup Environ Med*; 56: 197–201.
- Pavlovic M, Spasojevic M, Tasic Z, Tacevic S. (2001) Bronchial hyperactivity in bakers and its relation to atopy and skin reactivity. *Sci Total Environ*; 270: 71–5.
- Prichard MG, Ryan G, Musk AW. (1984) Wheat flour sensitisation and airways disease in urban bakers. *Br J Ind Med*; 41: 450–4.
- Rosenberg N, Rameix F, Demangeat G, *et al.* (1991) Prévalence de l'allergie respiratoire dans la boulangerie-pâtisserie parisienne en 1987. *Arch Malad Prof*; 52: 33–6.
- Sanchez-Monge R, Garcia-Casado G, Lopez-Otin C, Armentia A, Salcedo G. (1997) Wheat flour peroxidase is a prominent allergen associated with baker's asthma. *Clin Exp Allergy*; 27: 1130–7.
- Smith TA, Smith PW. (1998) Respiratory symptoms and sensitization in bread and cake bakers. *Occup Med*; 48: 321–8.
- Thiel H, Ulmer WT. (1980) Bakers' asthma: development and possibility for treatment. *Chest*; 78: 400–5.
- Toren K. (1996) Self reported rate of occupational asthma in Sweden 1990–2. *Occup Environ Med*; 53: 757–61.
- Vanhanen M, Tuomi T, Hokkanen H, *et al.* (1996) Enzyme exposure and enzyme sensitisation in the baking industry. *Occup Environ Med*; 53: 670–6.
- Zuskin E, Mustajbegovic J, Schachter EN, Kern J. (1994) Respiratory symptoms and ventilatory function in confectionery workers. *Occup Environ Med*; 51: 435–9.