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PEAK EXPOSURE CONCENTRATIONS OF DUST AND FLOUR AEROALLERGEN IN FLOUR MILLS AND BAKERIES

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Abstract—As part of an epidemiological study amongst workers exposed to flour we measured peak exposure levels to total dust and flour aeroallergen with personal samplers in bakeries, flour mills and packing stations Short-term tasks which were expected to give rise to high concentrations of exposure (peaks) were identified. The frequency and duration of these tasks were estimated and their levels of exposure to dust and flour aeroallergen measured. In total 209 samples were taken. The highest exposure concentrations both for dust (geometric mean >30 mg m^{-3}) and for flour aeroallergen (geometric mean >500 μg m^{-3}) were measured during certain operations. Exposure concentrations for the tasks were often much higher than the levels we had measured over a shift in a previous study. This might be important for sensitization and for the development of asthma. Peak exposure concentrations could be used to explore the exposure–response relationship more comprehensively. In general average flour aeroallergen concentrations increased linearly with average dust concentrations, although there were some exceptions.

INTRODUCTION

As part of an epidemiological study to explore the relationship between occupational exposure to flour and respiratory, eye and skin symptoms and skin sensitivity we measured personal peak exposure concentrations to total dust and flour aeroallergen in several British flour mills and bakeries. We have previously reported the exposure concentrations for dust and flour aeroallergen measured over a shift for the bakeries and flour mills in this study (Nieuwenhuijsen, 1993; Nieuwenhuijsen *et al.*, 1994) and their association with sensitization and work-related symptoms (Cullinan *et al.*, 1994). Little is known about the duration, concentration and frequency required for sensitization or for the development of asthma. To explore this relationship in more detail during a shift, exposure concentrations were measured during short-term tasks, which were expected to cause high peak exposure concentrations. This paper describes the peak intensity measurements used to provide exposure estimates for subjects in the epidemiological study, and the relationship between total dust and flour aeroallergen concentrations.

Bakers' asthma was described in antiquity (Ramazzinni, 1940) and remains among the commonest causes of occupational asthma in Britain today (Meredith *et al.*, 1991). Several studies have shown that flour inhaled at work can cause specific immunological changes, respiratory symptoms and asthma, probably determined at least in part by the

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duration and intensity of exposure (Musk *et al.*, 1989; Järvinen *et al.*, 1979; Hartmann, 1986; Herxheimer, 1973).

Flour and its additives contain many antigens (Pfeil *et al.*, 1990; Brisman and Belin, 1991) but an assay to measure flour antigens has been developed only recently (Tee *et al.*, 1992; Sandiford *et al.*, 1994), and hitherto total dust concentration has been used as a surrogate (Musk *et al.*, 1989; Hartmann, 1986).

In our previous report, describing dust and flour aeroallergen exposure concentrations measured over a shift (Nieuwenhuijsen, 1993; Nieuwenhuijsen *et al.*, 1994), there were considerable differences in exposure concentrations between exposure groups but not, except for one old site, between sites. The relationship between total dust and flour aeroallergen concentrations varied between different production areas and depended on usage of products other than flour. Other studies, which have reported concentrations of flour dust, have shown considerable differences in exposure concentrations between jobs and tasks in different areas of flour mills and bakeries (Musk *et al.*, 1989; Hartmann, 1986; Masalin *et al.*, 1988; Awad el Karim *et al.*, 1986; Houba and Zweers, 1988; Gimenez, 1991). The great majority of measurements in these studies were taken over a shift and a few during defined tasks.

MATERIALS AND METHODS

Exposure measurements

We surveyed three large modern British bakeries (between 200 and 450 employees each), one flour mill with flour packing station (60 employees) and a flour packing station (30 employees). Two flour mills had left the study since our first visit. As previously described (Nieuwenhuijsen, 1993; Nieuwenhuijsen *et al.*, 1994) an occupational hygienist (M. J. Nieuwenhuijsen) visited each site and divided the employees into exposure groups, 11 in each flour mill and packing station and 15 in each bakery, using the zoning strategy described by Corn and Esmen (1979) and the uniform task categories described by Esmen (1984). Within each exposure group an expert panel (M. J. Nieuwenhuijsen, G. Hearn and L. Knowles) identified tasks which they expected would be associated with levels of exposure greater than the shift averages (Tables 1 and 2). An estimation of frequency of occurrence and duration was given by one of the panel members (MJN) (Tables 1 and 2).

Workers undertaking these tasks were invited to wear a personal sampler (Casella AFC123, Casella London Ltd, Bedford, U.K.) for the duration of the task. The personal samplers were connected to seven-hole sampling heads (Casella London Ltd, Bedford, U.K.) containing polytetrafluoroethylene (PTFE) filters (1.2 μm pore size, 25 mm dia.; Sartorius Instruments Ltd, GB-Belmont, Surrey, U.K.) at a flow rate of 2 l. min^{-1}. The aim was to obtain at least five samples for each task. For total dust quantification the filters were weighed before and after sampling on a six figure balance (Sartorius R180D; Sartorius Instruments Ltd, GB-Belmont, Surrey, U.K.) and returned to the laboratory for elution and flour aeroallergen quantification. Samples less than the detection limit were assigned half this value.

Elution and assay

For the flour aeroallergen assay, female Half-Lop rabbits were immunized with a mixture of wholemeal and hard white wheat bread flours (Telford's Bakery,

Table 1. Exposure groups and tasks with elevated levels of flour exposure in the flour mill and packing stations

Exposure group	Tasks	Task code	Frequency	Duration
1. Wheat millers	Loading/unloading wheat	A1	4/day	30 min
	Cleaning floor	B1	1/day	30 min
	Cleaning elevators	B2	1/year	30 min
	Spillage/chokes cleaning	B3	variable	variable
2 Flour millers	Tipping additives gluten, amylase, vitamix	C1	1/day	20 min
	Security flour tipping	C2		
	Spillage/chokes cleaning	B3	variable	variable
	Cleaning sifters	B4	1/month	4 h
	Cleaning floor	B5	1/day	30 min
	Cleaning dust collectors	B6	1/month	4 h
3. Mixing	Tipping additives, bags disposal	C3	8/shift	15 min
	Cleaning floor	B7	1/shift	20 min
4. Packing area	Bagging off	D	1/shift	2 h
	Cleaning	B8	1/shift	20 min
	Ripping/tipping	C4	variable	variable
5. Forklift truck/warehouse	Spillage/chokes cleaning	B3		variable
	Bag disposal	B9	variable 4/shift	5 min
6 Quality control lab	Grinding/sifting samples	E	8/shift	10 min
	Cleaning benches	B10	8/shift	5 min
7. Transport	Cleaning tankers	B11	1/month	2 h
	Loading/unloading flour	A2	2/shift	20 min
8. Hygiene	Cleaning floor			
	wheat mill	B1	1/shift	1 h
	flour mill	B5	1/shift	2 h
	mixing area	B7	1/shift	30 min
	Spillage/chokes cleaning	B3	variable	variable
	Cleaning sifters	B4	1/month	4 h
	Cleaning dust collectors	B6	1/month	4 h
	Bag disposal	B9	4/shift	5 min
9. Office				
10 Maintenance/ engineering	Elevator/chokes breakdowns	B12	variable	variable
	Maintenance cleaning	B13	variable	variable
11. Miscellaneous	Supervising tankers unloading wheat	A1	4/day	30 min

Maidstone, Kent, U.K.). When an IgG antibody titre of 1:1024 was reached the rabbit antisera were purified using caprylic acid and ammonium sulphate precipitation, followed by dialysis, freeze drying and storage at −20°C. Canadian Western Red Spring (CWRS) wholemeal flour was obtained additive free from the Flour Milling and Baking Research Association (Chorleywood, U.K.). Following overnight extraction in 0.1 M ammonium hydrogen carbonate, pH 7.65, the flour solution was centrifuged, dialysed and freeze dried, and stored at −20°C. The material sampled in the bakeries and mills was eluted from the PTFE filters using 0.5% v/v Tween 20 in 2 ml 0.1 M ammonium hydrogen carbonate, pH 7.65. The allergen content was measured using an inhibition assay (Sandiford *et al.*, 1994) with CWRS wholemeal flour extract coated to

Table 2 Exposure groups and tasks with elevated levels of flour exposure in the bakeries

Exposure group	Tasks	Task code	Frequency	Duration
1. Dispense/mixing	Tipping, weighing, sifting, bag disposal, mixing	A	8/shift	30 min
	Floor cleaning	B1	1/shift	20 min
2. Bread production	Dusting flour	C1	1/day	30 min
	Floor cleaning	B2	1/shift	20 min
3. Bread wrapping	Floor cleaning	B2	1/shift	20 min
4. Roll production	Dusting flour	C2	8/shift	10 min
	Floor cleaning	B2	1/shift	20 min
5. Roll wrapping	Floor cleaning	B2	1/shift	20 min
6. Confectionery/ dough brake	Dusting flour	C3	16/shift	10 min
	Floor cleaning	B2	1/shift	20 min
7. Confectionery/ flour involved	Dusting flour	C3	8/shift	2 min
	Floor cleaning	B2	1/shift	20 min
8. Confectionery/no flour				
9. Despatch				
10 Hygiene inside production areas	In depth cleaning:			
	silo	B3	1/month	4 h
	machinery bread	B4	1/week	4 h
	machinery roll	B5	1/week	4 h
	machinery confectionery	B6	1/week	4 h
	bins	B7	1/week	2 h
	Floor cleaning			
	mixing area	B1	1/shift	4 h
	production area	B2	1/shift	4 h
	Breakdown cleaning	B8	variable	variable
11. Hygiene outside production areas	Bag disposal	D	2/day	5 min
12. Maintenance/ engineers	Breakdowns/blockages cleaning	B8	variable	variable
13. Quality control lab				
14. Office				
15. Miscellaneous				

plates (100 μl), a CWRS wholemeal flour standard curve (11 dilutions) or reconstituted filter extract (100 μl) and purified rabbit IgG antibody (100 μl). Detection of antibody binding was accomplished using ^{125}I Protein-A (Amersham, U.K.). The assay had upper and lower detection limits of 200 and 1 $\mu g\ ml^{-1}$, respectively. The standard curves were generated using the gamma counter (Cobra 5005 Packard) Four Parameter Logistic fitting software. The flour aeroallergen concentration was calculated via the standard curve and corrected for the volume of air sampled and the reconstitution volume of the eluted filter.

Statistical analysis

The statistical software package SAS (SAS Institute Inc., Cary, North Carolina, U.S.A.) was used for statistical analyses. Regression analysis was used to assess the relation between dust and flour aeroallergen. The regression equation was used to predict flour aeroallergen levels for tasks where there were no measurements available.

RESULTS

Total dust levels

In all, 209 dust samples were collected (Tables 3 and 4). In the flour mills and packing stations the highest dust concentrations [geometric mean (GM)> 30 mg m^{-3}] were measured during cleaning operations; in particular in dust collector, spillage and chokes, flour tanker and maintenance cleaning (Table 3). Also in the bakeries the highest concentrations were measured during cleaning operations; in particular bins and flour silo cleaning (Table 4). Both in the bakeries and in the flour mills some tasks, for example elevator breakdown cleaning, bag disposal and wheat unloading, were not measured because either they did not occur during the sampling period, or they were of too short a duration to measure, or only a few subjects in our study undertook these tasks. For these tasks the concentrations were estimated using company records and personal expertise.

Flour aeroallergen levels

Flour aeroallergen concentrations followed a pattern similar to that of the total dust concentrations (Tables 3 and 4). Again both for the bakeries and for the flour mills the highest concentrations were meaured during cleaning operations. For those tasks for which there were no measurements available the flour aeroallergen concentrations were estimated using the equation of a regression model which used the log transformed GMs of dust from the 'measured' tasks as an independent variable and the log transformed GMs of the flour aeroallergen as dependent variable. This equation [(ln GM flour aeroallergen) $= 4.54 + 0.04 * $ (ln GM dust)] estimated the flour aeroallergen concentrations using the assigned values for the GMs of dust.

Figure 1 shows a plot of the GMs of flour aeroallergen against the GMs of dust for the various task (GMs from Tables 3 and 4). As can be seen from the figure for the majority of tasks there appeared to be a linear increase for flour aeroallergen concentrations with dust concentrations. There were a few exceptions with tasks where dust concentrations were high and flour aeroallergen concentrations relatively low and vice versa.

DISCUSSION

This paper has reported the frequency, duration and intensity of short-term peak exposure to dust and flour aeroallergen in bakeries, flour mills and packing stations. We have previously reported the exposure to dust and flour aeroallergen measured over a shift (Nieuwenhuijsen *et al.*, 1994) and its relationship with sensitization and work-related symptoms (Cullinan *et al.*, 1994). Exposure measures from this report will allow more comprehensive exploration of the relationship between exposure to dust and flour aeroallergen and sensitization and asthma.

This is the first report that shows a comprehensive picture of frequency, duration and concentration of peak exposures to dust and flour aeroallergen in bakeries, flour

Table 3. Task groups, dust concentrations (mg m^{-3}) of task measurements and the number of measurements taken in the flour mills and packing stations

Task group		Task	Dust *N*	AM	GM	GSD	Range	Flour aeroallergen *N*	AM	GM	GSD	Range
A Loading/unloading	A1	Wheat	0		40*					464.1*		
	A2	Flour	4	19 1	18.1	1.4	11.6–25.6	2	519.8	519.7	1.0	511.5–528.6
B Cleaning	B1	Wheat mill floor	0		15*					170.7*		
	B2	Wheat mill elevators	0		20*					208.5*		
	B3	Spillage/chokes	3	57.3	39.3	2.8	18.4–127.8	3	4492.1	3807.9	2.0	2483.6–8321.0
	B4	Flour mill sifters	12	39.8	28.5	2.3	9.4–134.5	11	682.7	236.7	6.3	5.0–3406.6
	B5	Flour mill floor	5	26.5	12.9	4.0	3.7–64.1	5	1456.7	234.4	7.1	41.9–6826.5
	B6	Flour mill dust coll	8	52.0	34.0	2.6	11.9–160.0	7	1368.3	1149.3	1.9	356.1–2934.1
	B7	Mixing area floor	6	14.1	12.9	1 6	5.6–21.0	6	275.6	141.5	4.6	15.7–583.1
	B8	Packing area floor	7	20.1	13.9	2.5	5.0–47.6	7	631.2	427.7	2.5	152 5–1643.9
	B9	Bag disposal	1	0.4	10*			1	6 5	139.8*		
	B10	Lab benches	0		10*					139.8*		
	B11	Flour tankers	2	67.8	65.1	1 5	49.0–86.6	2	181 9	174.3	1 5	129.9–234.0
	B12	Elevator/chokes breakdowns	0		40*					464.1*		
	B13	Maintenance cleaning	3	186.7	97.2	4.2	26.5–458.0	3	4237.8	3606.0	2.1	1586.8–6747.0
C Tipping	C1	Flour mill additives	5	10.9	8.8	2.2	3 5–19.5	5	162.9	63.6	4.1	18.0–652.7
	C2	Security flour	1	8.1				1	1436.8			
	C3	Mixing area additives	14	15.7	4.1	11.2	0.1–90.3	14	150.8	104.7	2.6	15.2–445.0
	C4	Ripping/tipping pack	7	22.7	21.2	1.5	10.5–39.6	7	420.0	405.8	1.3	283.5–629 7
D Bagging off	D	Bagging off	10	6.6	5 5	1.9	2.4–17.9	10	216.7	183.8	1.7	94.4–655.0
E Grinding/sifting	E	Laboratory grinding/sifting flour	4	17.2	11.7	2.6	4.4–45.0	4	337.8	273.1	2.1	137.3–743.0
Five task groups		21 tasks	81	samples				77	samples			

*Assigned value.

A2, B3, B8, B13 had, respectively, two, two, six and one measurements discarded because they were overloaded. GMs including these measurements would have been 32.2, 107.3, 38.1 and 185.7 mg m^{-3} for dust and 777.2, 3620.0, 849.5 and 3606 0 μg m^{-3} for flour aeroallergen.

N = number of samples.

GM = geometric mean.

AM = arithmetic mean.

GSD = geometric standard deviation.

Table 4. Task groups, dust concentrations (mg m^{-3}) of task measurements and the number of measurements in the bakeries

Task group		Task	Dust					Flour aeroallergen				
			N	AM	GM	GSD	Range	*N*	AM	GM	GSD	Range
A Tipping	A	Tipping/weighing/sifting/ bag disposal/mixing	32	13.5	7.3	3.6	0.3–53.5	32	481.7	269.8	3.4	13.6–2301.3
B Cleaning	B1	Dispense/mix. floor	7	13.7	8.3	3.4	1.3–33.2	7	956.5	415.9	4.0	75.6–3657.7
	B2	Production floor	18	2.3	1.4	3.3	0.1–8.4	18	29.3	18.6	3.2	2.5–69.0
	B3	Flour silo	4	29.1	23.4	2.3	7.6–54.4	4	831.8	654.5	2.2	313.3–1862.9
	B4	Bread machinery	8	5.0	1.8	3.4	0.7–31.3	8	110.4	20.7	5.4	4.3–756.4
	B5	Roll machinery	5	6.5	5.3	2.1	1.9–11.4	5	156.7	107.9	2.7	33.0–374.2
	B6	Confectionery machinery	4	2.0	1.8	1.6	1.2–3.6	3	30.0	29.7	1.2	24.4–33.6
	B7	Bins	5	99.8	42.9	3.8	10.7–387.8	2	1293.8	1138.5	2.1	679.2–1908.3
	B8	Breakdown/blockages		dno	40*					464.1*		
C Flour dusting	C1	Bread production	9	11.8	9.0	2.3	2.2–25.0	9	214.5	185.5	1.7	85.7–523.1
	C2	Roll production	17	18.1	8.8	3.5	1.3–80.7	17	301.8	163.1	2.9	36.1–1933.2
	C3	Dough brake	19	6.2	4.2	2.5	0.9–21.1	19	192.4	118.5	3.0	7.0–684.2
D Bag disposal	D	Bag disposal		tstm 10*						139.8*		
Four task groups		13 tasks	128 samples					124 samples				

dno = did not occur.
tstm = too short to measure.
*Assigned value.
A had one measurement discarded because it was overloaded. GM including this measurement would have been 7.1 mg m^{-3} for dust and 265.7 $\mu g\ m^{-3}$ for flour aeroallergen.
N = number of samples.
GM = geometric mean
AM = arithmetic mean
GSD = geometric standard deviation.

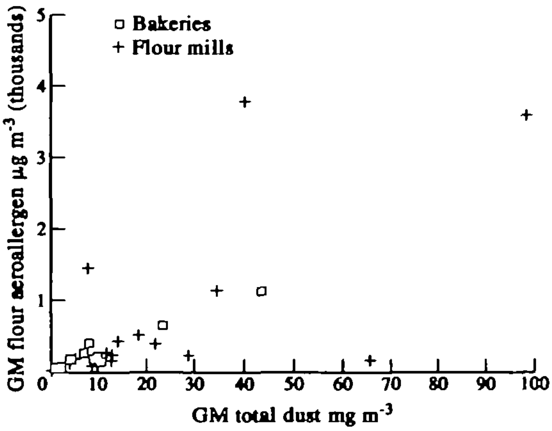

Fig. 1. Plot of the geometric means of the total dust levels against the geometric means of the flour aeroallergen levels.

mills and packing stations. Hartmann (1986) and Gimenez (1991) showed concentrations of dust exposure for a few tasks but the numbers of measurements were small. Our measurements indicate that the highest concentrations of dust and flour aeroallergen exposure are associated with cleaning operations, and that measured over short periods these concentrations were much higher than those which we previously measured over a shift (Nieuwenhuijsen *et al.*, 1994). For example, concentrations of dust and flour aeroallergen measured over a shift for hygiene workers (cleaners) were 1.7 mg m^{-3} and 148.6 μg m^{-3}, respectively. During short-term cleaning operations such as cleaning the silo or bins these levels were much higher: 29.1 and 42.9 mg m^{-3}, respectively, for dust; and 654.5 and 1138.5 μg m^{-3} for flour aeroallergen. This could be important for sensitization or development of asthma, although little is known about the frequency, duration and intensity required.

Although our aim was to obtain at least five samples for every task, this could not always be achieved. For some tasks we were unable to obtain any samples, either because they did not occur during the sampling period, were too short to measure, or only a few subjects in our study performed them. Dust concentrations for these tasks were estimated from company records. Flour aeroallergen concentrations were estimated using the equation from a regression analysis with the 'measured' levels of dust and flour aeroallergen. This is likely to be appropriate as 'measured' flour aeroallergen concentrations in general increased linearly with 'measured' dust concentrations, although there were some exceptions.

The frequency and duration of the tasks are estimates and were obtained by observation. These estimates might be different at other sites as might be the concentrations of exposure. Even within an exposure group the frequency and duration might be different for different workers for short periods. These estimates are averages over a longer period and over different sites. Certain tasks such as breakdown cleaning are almost impossible to predict but might be responsible for the highest exposure.

As in our previous report (Nieuwenhuijsen *et al.*, 1994) in general average concentrations of flour aeroallergen appear to increase linearly with average dust concentrations, although there were some exceptions.

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