Exposure to Flour Dust and Sensitization Among Bakery Employees

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Background *The National Institute for Occupational Safety and Health conducted a study to determine prevalences of sensitization to bakery-associated antigens (BAAs) and work-related respiratory symptoms at a large commercial bakery.*

Methods *The following measurements were carried out: personal breathing zone (PBZ) and general area (GA) monitoring for inhalable flour dust, α-amylase and wheat, a questionnaire, and blood tests for IgE specific to flour dust, wheat, α-amylase, and common aeroallergens.*

Results *Of 186 bakery employees present during our site visit, 161completed the questionnaire and 96 allowed their blood to be drawn. The geometric mean PBZ and GA inhalable flour dust concentrations for the lower-exposure group was 0.235 mg/m^3, and for the higher-exposure group was 3.01 mg/m^3. Employees in the higher-exposure group had significantly higher prevalences of work-related wheezing, runny nose, stuffy nose, and frequent sneezing than the lower-exposure group. The prevalence of IgE specific to wheat was significantly higher among employees who ever had a job in the higher-exposure group or in production at another bakery at both the $\geq$ 0.10 kU/L and the $\geq$ 0.35 kU/L cutoffs, and to flour dust and α-amylase at the $\geq$ 0.10 kU/L cutoff, compared to the lower-exposure group.*

Conclusions *Despite knowledge of the risks of exposure to flour being available for centuries, U.S. employees are still at risk of sensitization and respiratory symptoms from exposure to high levels of BAA.* Am. J. Ind. Med. 53:1225–1232, 2010. © *2010 Wiley-Liss, Inc.*

KEY WORDS: flour; α-amylase; wheat; asthma; rash; respiratory; bakers; sensitization

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) received a confidential employee request for a health hazard evaluation at a large commercial bakery [NIOSH, 2009]. The request concerned about respiratory symptoms among the employees. This article is excerpted from that health hazard evaluation report. Baker's asthma is one of the most common forms of occupational asthma. Ramazzini was the first to describe baker's asthma in 1700. Case reports from the beginning of the 20th century established it as an allergic disease because of the observed combination of positive skin tests to flour extracts and respiratory symptoms suggestive of asthma [Brisman, 2002]. Despite the fact that the risks of exposure to bakery dust have been known for centuries, the incidence of baker's asthma appears to be steadily increasing [Houba et al., 1998a].

Rhinitis among bakers is common and usually precedes asthma. Conjunctivitis and skin symptoms may also occur. Atopy is a risk factor, but gender, age, and smoking habits do not have a significant influence on sensitization or disease

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Contract grant sponsor: NIOSH; Contract grant number: Y1-ES-0001; Contract grant sponsor: NIEHS; Contract grant number: Y1-ES-0001.
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Accepted 24 July 2010
DOI 10.1002/ajim.20893. Published online 22 September 2010 in Wiley Online Library (wileyonlinelibrary.com).

[De Zotti et al., 1994; Baur et al., 1998; Houba et al., 1998b]. Symptoms develop after a latency period of months or years, even decades, and risk increases with increased exposure. In addition to allergy, non-specific mucous membrane and respiratory irritation also occur frequently among bakers, possibly more commonly than allergic symptoms [Houba et al., 1998a].

Wheat and other cereal flours are the main causes of baker's allergy. Wheat flour is a complex mixture that contains at least 40 allergens [Sander et al., 2001]. Other common allergens in bakeries are the enzymatic dough improvers, of which fungal or bacterial α-amylase is the most frequently reported cause of allergy. Epidemiologic studies have demonstrated prevalences of sensitization of 5–28% to wheat and 2–16% to α-amylase [Houba et al., 1996]. Variability in these prevalences is due to use of different methodologies for measuring sensitization between studies and possibly to differences in exposure. The prevalences of sensitization to bakery associated antigens (BAA), allergy, and asthma among bakers in the US are unknown, as is the range of exposures encountered in US bakeries.

The federal Occupational Safety and Health Administration (OSHA) considers flour dust as general nuisance dust (particulates not otherwise regulated); therefore, the permissible exposure limit (PEL) is 15 mg/m^3. The California OSHA (CalOSHA) PEL and the American Conference of Governmental Industrial Hygienists® (ACGIH) threshold limit value® (TLV) for inhalable flour dust are 0.5 mg/m^3. British Columbia, Ontario, Hong Kong, and Ireland also have occupational exposure limits for inhalable flour dust of 0.5 mg/m^3. No occupational exposure limits specific for α-amylase or wheat have been proposed.

Background sensitization is also found in the general population. A study of 416 animal laboratory employees documented that 1.7% had positive skin prick tests to fungal α-amylase and 2.1% to wheat [Houba et al., 1996]. One study demonstrated sensitization prevalences to wheat of 1.2% for animal health apprentices and 4.1% for dental hygiene apprentices [Gautrin et al., 1997]. A NIOSH study of 534 blood donors demonstrated the prevalences of specific immunoglobulin E (IgE) to wheat (3.6%), flour (5.8%), and α-amylase (1.0%) [Biagini et al., 2004].

Process Description

This bakery makes bread and buns and employs over 200 people in management and administrative positions, sales, transportation, maintenance engineering, sanitation, and production. The production employees are further divided into those working on the bread and bun lines, in packaging, and in distribution. Approximately 155 production employees and 18 maintenance engineers work at this facility.

Loaf bread is made in the bread line, and hamburger and hot dog buns are made in the bun lines. The plant operates 24 hr a day, 7 days a week, with the bread line operating approximately 120 hr and the bun line operating approximately 130–140 hr before shutdown and cleaning. At any one time, approximately 18 employees each work on the bread and the bun lines, including those directly involved with baking, packaging, and distribution.

The entire baking process takes approximately 7 hr, and wheat flour is the most frequently handled product. The term flour is used throughout this report to refer to wheat flour. The sponge (a mixture of flour, water, and various additives) is fermented for 3–4 hr. Flour is pneumatically added to the sponge in a mixer to produce dough. In some instances, powdered ingredients are manually added to the mixer directly from bags or after being hand-weighed into 5-gallon buckets. Local exhaust ventilation is not used during the manual handling of ingredients. The dough mix is then made into loaves or buns and baked. The baked bread and buns are cut, inspected, bagged, and sent to shipping.

Sanitation is performed on two shifts each week and includes both dry and wet clean-up methods. In the area where dough is mixed, overhead pipes, conveyers, and equipment are blown off with compressed air. Following the removal of dust with the compressed air, the area is dry swept and then scrubbed/hosed down with a mixture of detergents, sanitizers, and water. In other areas of the plant, dry cleaning techniques are used including blowing off equipment with compressed air and dry sweeping. A mixture of detergents, sanitizers, and water are then used for wet cleaning; however, they are only applied as needed to smaller, localized areas.

MATERIALS AND METHODS

Objectives

The objective of this study was to determine if a health hazard due to exposure to BAA (flour dust, wheat, and fungal α-amylase) existed in this large, commercial bakery in the United States, and to provide recommendations to reduce exposure. Secondarily, we wanted to see if, despite centuries of knowledge about the hazards of exposure to flour dust, US employees are still at risk of sensitization and respiratory symptoms from exposure to high levels of BAA. Finally, we wanted to determine if respiratory symptoms among employees were related to sensitization to BAA.

Study Population

The study population included all employees of the bakery. All employees were asked to participate in order to compare sensitization and symptom prevalences between groups of employees with different levels of exposure to bakery antigens, and to most accurately characterize exposure in the different departments of the bakery. We observed the process in the bakery and also used information

in the scientific literature to assign ''lower-exposure'' and ''higher-exposure'' categories to participants. Exposure data from several studies documents that front-end (i.e., before the oven) bakery workers have the highest dust exposure [Burdorf et al., 1994; Nieuwenhuijsen et al., 1994; Houba et al., 1997; Baatjies et al., 2010]. The lower-exposure group included employees who worked in the office areas (sales, plant management, and administrative employees) and those in production management, transportation, distribution, bread or bun wrap, and oven areas (oven and pan stacker employees). These employees either did not handle the product at all or only handled baked bread or buns, not dough. The higher-exposure group included the remainder of bread and bun production employees and forepersons, sanitation, and engineers. These employees either handled raw ingredients and/or dough or came in contact with the machinery that handled ingredients or dough. Persons who reported prior job assignments at this bakery that fell into the higher-exposure group or who had worked in production at another bakery were assigned to the past higher-exposure group.

Informed Consent and Notification

The primary intent of health hazard evaluations is to determine the health risk among a defined group of workers and not contribute to generalizable knowledge. Therefore, this activity was considered public health practice, not research, and did not require review by the NIOSH Human Subjects Review Board. All participants in this health hazard evaluation did provide informed consent, however, and the health hazard evaluation program consent forms are reviewed by the NIOSH Human Subjects Review Board annually. Each study participant was informed in writing of the results of his or her serum tests and what they meant.

Biological Samples

Approximately 15 ml of whole blood were collected from each of the participants who consented to have blood drawn. Venipuncture was performed by trained technicians following the universal precautions for working with blood and blood products specified by the Centers for Disease Control and Prevention and OSHA [CDC, 1998; 29 CFR, 1910.1000]. After venipuncture, the blood was centrifuged and the serum transported to the NIOSH laboratory for analysis. Serum was tested for total IgE; IgE specific to flour, wheat, and α-amylase; and for a variety of common aeroallergens to assess atopy.

Specific IgE was measured using an IMMULITE® 2000 3gAllergy™ instrument (DPC, Los Angeles, CA). The IMMULITE 2000 is a Food and Drug Administration (FDA) cleared enzyme-enhanced chemiluminescent enzyme immunoassay that quantifies specific IgE antibody. Briefly, a streptavidin-coated bead, biotinylated liquid allergen, and serum sample are incubated for 30 min. After a spin wash, an alkaline phosphatase-labeled monoclonal antibody specific for human IgE is added and another 30-min incubation follows. The bead is washed again, and the enzyme label is measured with a chemiluminescent substrate (phosphate ester of adamantyl dioxetane). Specific IgE was measured against the following allergens: fungal α-amylase (K87M), flour (K301M), and wheat (F4M). Specific IgE calibrators and positive controls are included with the kit. A negative serum control (human serum with no detectable allergen-specific IgE) and an internal positive quality control serum sample (serum positive to *Dermatophagoides farinae*), recommended by the manufacturer, is also run in all assays.

The IMMULITE 2000 has an FDA-cleared cutoff of 0.10 killiunits per liter of serum (kU/L) IgE. The insert for the IMMULITE 3gAllergy Specific IgE Universal Kit describes two scoring systems, both of which classify specific IgE levels $\geq$0.10–0.34 kU/L (standard classification) and $\geq$0.11–0.24 kU/L (extended classification) as very low. Traditionally, a level $\geq$0.35 kU/L is considered Class 1, or positive.

Atopy was measured using the IMMULITE 2000 AlaTOP Allergy Screen for 12 allergens. This method is a FDA-cleared qualitative chemiluminescent enzyme-labeled sequential immunoassay, based on liquid ligand-labeled allergens, monoclonal antibodies, and separation by anti-ligand coated solid phase. The allergens are covalently bound to a soluble polymer/copolymer matrix, which in turn is labeled with a ligand; anti-ligand is coated on the polystyrene bead to capture the ligand-labeled allergens. The 12 allergens included on the matrix are *D. pteronyssinus* (dust mite), cat epithelium, dog dander, *Cynodon dactylon* (Bermuda grass), *Phleum pretense* (timothy grass), *Penicillium chrysogenum*, *Alternaria tenuis*, *Ambrosia artemisiifolia* (common ragweed), *Plantago lanceolata* (English plantain), *Parietaria officinalis* (wall pelitory), *Betula papyrifera* (paper birch), and *Cryptomeria japonica* (Japanese cedar). A positive and negative reference serum is included in each assay. A reactive result indicates that antibodies to one or more of the component allergens in the panel are present in the patient sample, and that patient is classified as atopic. A non-reactive result indicates non-detectable antibodies to the component allergens.

Questionnaire

All participants in this evaluation completed a questionnaire. Its questions concerned demographics (age, sex, job title, years worked, and work department); personal history of allergies, eczema, asthma, and smoking; having upper and lower respiratory symptoms at work in the last month (unrelated to a cold or respiratory infection); and whether those symptoms got better on days off work. Symptoms were considered work related if they were present at work and improved on days away from work. Participants were classified as current, former, or never smokers.

Industrial Hygiene

Personal breathing zone (PBZ) and general area (GA) air sampling were conducted to characterize employees' overall exposures to BAA. Full shift PBZ and GA air measurements for inhalable flour dust were collected in the bread and bun production, distribution, engineering, and sanitation departments; and the office and plant management areas. While both PBZ and GA samples were taken in multiple work areas, GA samples were primarily taken in areas where exposure was thought to be low (i.e., office areas). No measurements were taken for transportation workers because they do not work in the bakery building, but drive trucks to deliver product to retailers.

Inhalable flour dust samples were collected using Institute of Medicine (IOM) samplers with Teflon® filters (pore size 1.0 μm with laminated polytetrafluoroethylene support). Samples were connected to personal sampling pumps calibrated to a flow rate of 2 L/min. IOM cassettes were changed throughout the shift to prevent overloading the sampling media.

Inhalable flour dust samples were stored at ambient temperatures in sealed containers to prevent additional exposure to moisture during storage and shipment. A recording high–low thermometer was added to all shipping containers to record maximal temperature transients of the samples. The samples were first analyzed by the NIOSH contract lab for inhalable flour dust (weight gain). The flour dust samples had a limit of detection that ranged from 46 to 100 μg and a limit of quantitation that ranged from 150 to 350 μg, depending on the batch.

Following the weight gain analysis, the inhalable flour dust samples were then shipped to the Institute for Risk Assessment Sciences, University of Utrecht, Utrecht, the Netherlands, where they were analyzed using the methods outlined below for α-amylase and wheat allergens.

Wheat allergens were recovered from the filters by extraction with 2.5 ml of 0.15 M phosphate-buffered saline (pH 7.4), and concentrations were measured in the extract by inhibition immunoassay, using a pool of human immunoglobulin G4 polyclonal antibodies. The limit of detection for this method was 50 ng/ml [Houba et al., 1996]. The α-amylase allergens were measured using a sandwich enzyme immunoassay with affinity-purified polyclonal rabbit IgG antibodies. The limit of detection for this method was 100 pg/ml [Houba et al., 1997].

Statistical Analysis

SAS Version 9.1.3 software (SAS Institute, Cary, NC) and StatXact Version 6 software (Cytel Software Corporation, Cambridge, MA) were used for the statistical analyses. Results with $P \leq 0.05$ were considered statistically significant. Geometric means and medians are reported for environmental samples because some distributions were lognormal and others were not. Prevalence ratios (PRs) were used to compare the prevalence of symptoms and the prevalence of sensitization to BAA between exposure groups. Along with the PR, a 95% confidence interval (95% CI) for the PR was calculated. The PR was considered statistically significant if the 95% CI did not include the number 1. Chi square or Fisher's exact tests were also used to compare the prevalence of sensitization to BAA between atopics and non-atopics, and the prevalence of self-reported, work-related symptoms among employees who are sensitized to flour dust, α-amylase, or wheat and those who are not. Total IgE was log normally distributed so we transformed the data, and used the Student's *t*-test to determine any difference between exposure groups. Pearson's correlation coefficient was used to determine the correlation between the log-transformed α-amylase and inhalable flour dust concentrations, and the log-transformed wheat and inhalable flour dust concentrations.

Statistical analysis of air sampling results included the use of imputed concentrations where the sample results were less than the limit of detection. For samples that were less than the limit of detection (i.e., non-detectable), a concentration was calculated by dividing the reported limit of detection by the square root of 2 and then by the individual sample volume [Hornung and Reed, 1990]. For samples between the limit of detection and limit of quantitation (i.e., trace), a concentration was calculated by dividing the estimated laboratory result by the individual sample volume. Concentrations for samples above the limit of quantitation were calculated by dividing the reported laboratory result by the individual sample volume. In this report, values less than the limit of quantitation are reported either as non-detectable or trace, not as the calculated concentration used in the statistical analysis.

RESULTS

Of 186 employees present in the bakery during the site visit, 161 (87%) completed the questionnaire. Of these, 96 allowed their blood to be drawn.

Demographic information for employees is provided in Table I. Employees showed no difference in mean age between the lower- and higher-exposure groups, and they were similar in sex distribution. Of employees in the higher-exposure group, 15% reported current asthma compared to 6% in the lower-exposure group; however, among persons who had never smoked, the difference was more pronounced (18% of the higher-exposure group compared to 2% of the lower-exposure group). Nobody reported being diagnosed with baker's asthma.

We collected 83 PBZ and 19 GA air measurements for inhalable flour dust in the bread and bun production, distribution, engineering, and sanitation departments; and

TABLE I. Demographic Information, by Current Exposure Group

	Higher-exposure group (n = 65–66)[a]	Lower-exposure group (n = 93–95)[a]
Mean age in years	44	44
Mean tenure	13 years	16 years
Male	89%	82%
Smoking status		
Never	50%	55%
Former	33%	23%
Current	17%	22%

[a]Denominators vary due to missing information.

the office and plant management areas. The samples were analyzed for α-amylase and wheat (see Table II).

Of the 23 PBZ measurements for employees in the lower-exposure group, eight reached or exceeded the CalOSHA PEL and ACGIH TLV of 0.5 mg/m^3 time weighted average (TWA) for inhalable flour dust. Of the 60 PBZ measurements for employees in the higher-exposure group, 56 reached or exceeded the CalOSHA PEL and ACGIH TLV for inhalable flour dust.

TABLE II. Air Sampling Results, by Exposure Group

	Higher-exposure group	Lower-exposure group
Number of personal breathing zone samples	60	23
Number of general area samples	6	13
Inhalable flour dust		
Geometric mean	3.01 mg/m^3	0.235 mg/m^3
Range	Trace to 65 mg/m^3	Non-detect to 1.4 mg/m^3
α-Amylase		
Geometric mean	2.10 ng/m^3	0.122 ng/m^3
Range	0.095–11,000 ng/m^3	0.019–1.2 ng/m^3
Wheat		
Geometric mean	12.6 μg/m^3	0.433 μg/m^3
Range	0.18–900 μg/m^3	0.14–3.6 μg/m^3

We also looked to see if the wheat and α-amylase concentrations correlated with the inhalable flour dust concentrations. The logs of wheat ($r = 0.93$, $P < 0.01$) and α-amylase ($r = 0.64$, $P < 0.01$) were positively correlated with the logs of the inhalable flour dust concentrations.

Employees in the higher-exposure group had higher prevalences of some work-related symptoms than those in the lower-exposure group (see Table III). This was most striking for work-related wheezing, with 15% of the higher-exposure group reporting work-related wheezing or whistling in the chest compared to 1% of the lower-exposure group (PR = 13.57; CI: 2.27, 174.40). Employees in the higher-exposure group also reported significantly more work-related runny nose, stuffy nose, and frequent sneezing (see Table III). We also calculated PRs for work-related cough, wheezing or whistling in chest, and shortness of breath while controlling for smoking; and the results were similar. Of the higher-exposure group, 27% reported having a rash on their face, neck, hands, or arms in the month prior to the study, compared to 14% of the lower-exposure group (PR = 1.99; CI: 1.05, 3.78).

Traditionally, a level ≥0.35 kU/L of specific IgE is considered a positive test, which means that the person is sensitized; however, the test we used (IMMULITE 2000) has an FDA-cleared cutoff of 0.10 kU/L IgE. Therefore, we report results at both cutoffs. The prevalences of IgE specific to wheat, flour dust, and α-amylase were higher in the higher-exposure group at both the ≥0.10 kU/L and the ≥0.35 kU/L cutoffs, but these differences were not statistically significant. A number of employees who had jobs in the lower-exposure group at the time of the site visit reported past work in a higher-exposure group job at this bakery or in production at another bakery. The prevalence of IgE specific to wheat was significantly higher among employees who reported either a current or past job in the higher-exposure group or

TABLE III. Prevalence of Work-Related Symptoms, by Current Exposure Group

Work-related symptom	Higher-exposure group (n = 61–64)[a], number (%)	Lower-exposure group (n = 91–93)[a], number (%)	Prevalence ratio (95% confidence interval)
Cough	8 (13%)	4 (4%)	3.00 (0.99, 11.42)
Wheeze or whistling in chest	9 (15%)	1 (1%)	13.57 (2.27, 174.40)
Unusual shortness of breath	7 (11%)	4 (4%)	2.56 (0.81, 10.68)
Runny nose	10 (16%)	4 (4%)	3.81 (1.25, 11.61)
Stuffy nose	11 (18%)	6 (6%)	2.75 (1.07, 7.05)
Sinus problems	10 (16%)	7 (8%)	2.05 (0.83, 5.11)
Dry or irritated eyes	12 (19%)	10 (11%)	1.78 (0.82, 3.86)
Frequent sneezing	13 (21%)	7 (8%)	2.68 (1.13, 6.34)

[a]Denominators vary due to missing information.

TABLE IV. Prevalence of Sensitization to Bakery-Associated Antigens, by Current And/Or Past Exposure Group

Measure of sensitization	Higher-exposure group (either current or past) (n = 63), number (%)	Lower-exposure group (n = 33), number (%)	Prevalence ratio (95% confidence interval)
IgE to α-amylase			
≥0.10 kU/L	7 (11%)	0	+inf[a] (1.02, +inf)
≥0.35 kU/L	4 (6%)	0	+inf (0.58, +inf)
IgE to flour			
≥0.10 kU/L	26 (41%)	5 (15%)	2.72 (1.15, 6.43)
≥0.35 kU/L	13 (21%)	2 (6%)	3.40 (0.82, 14.20)
IgE to wheat			
≥0.10 kU/L	23 (37%)	5 (15%)	2.41 (1.01, 5.75)
≥0.35 kU/L	17 (27%)	2 (6%)	4.45 (1.09, 18.12)

[a]Positive infinity or undefined.

in production at another bakery at both the ≥0.10 kU/L and the ≥0.35 kU/L cutoffs, and to flour dust and α-amylase at the ≥0.10 kU/L cutoff, compared to the lower-exposure group (see Table IV).

The prevalences of work-related wheezing were 3–5 times higher in employees sensitized to wheat than those that were not sensitized. The difference was statistically significant at the ≥0.10 kU/L cutoff for IgE but was not significant at the ≥0.35 kU/L cutoff ($P = 0.06$). The prevalence of work-related runny nose was significantly higher among those sensitized to wheat at the ≥0.35 kU/L cutoff, but not at the ≥0.10 kU/L cutoff ($P = 0.10$). The prevalences of work-related frequent sneezing were higher among wheat-sensitized persons but were not significant ($P = 0.11$ at the ≥0.35 kU/L cutoff and 0.09 at the ≥0.10 kU/L cutoff).

No statistically significant differences appeared in work-related symptom prevalences between those above and those below the cutoffs for sensitization to α-amylase. Work-related runny nose was significantly more prevalent among those sensitized to flour than those that were not sensitized ($P = 0.03$) at the ≥0.35 kU/L cutoff but was not significant at the ≥0.10 kU/L cutoff.

Atopy is the predisposition toward having allergic diseases. We determined whether employees were atopic by AlaTOP. We found no significant difference in the prevalence of atopy between groups when looking at the AlaTOP (47% [21/45] of the higher-exposure group vs. 41% [21/51] of the lower-exposure group, $P = 0.59$). Atopics were significantly more likely to be sensitized to wheat and flour at both the ≥0.10 kU/L cutoff and ≥0.35 kU/L cutoff and to α-amylase at the ≥0.10 kU/L cutoff.

DISCUSSION

Despite knowledge of the risks of exposure to flour being available for centuries, US employees are still at risk of sensitization and respiratory symptoms from exposure to high levels of BAA. A health hazard existed at this large, commercial bakery from exposure to BAA. The prevalences of sensitization to α-amylase and wheat at the ≥0.35 kU/L cutoff among the higher-exposure group in this evaluation are similar to those found in other studies of bakers, which have demonstrated prevalences of sensitization of 5–28% to wheat and 2–16% to α-amylase [Houba et al., 1996; Baatjies et al., 2009]. A NIOSH study of 534 blood donors demonstrated the prevalences of specific IgE to wheat, flour, and α-amylase of 3.6%, 5.8%, and 1.0%, respectively [Biagini et al., 2004]. These are similar to the prevalences of sensitization among the lower-exposure group at the ≥0.35 kU/L cutoff. While we categorized employees into exposure groups based upon our observations and reported findings from other bakeries, but we could have misclassified some employees. While the higher-exposure group had a geometric mean (GM) inhalable dust concentration 10 times higher than the lower-exposure group, there was overlap in our air sampling results between the upper range of the lower-exposure and the lower range of the higher-exposure groups. Atopics were significantly more likely to be sensitized to wheat and flour at both the ≥0.10 kU/L cutoff and ≥0.35 kU/L cutoff and to α-amylase at the ≥0.10 kU/L cutoff. This is consistent with past studies of bakery-associated allergy.

Few symptoms were significantly related to sensitization, and of those that were, no clear pattern of which cutoff was better emerged. The small number of participants in the evaluation very likely limited our ability to detect significant differences. Furthermore, sensitization to BAA usually happens before symptoms and asthma develop [Brant, 2005], so some employees in this bakery may be sensitized but asymptomatic. The cross-sectional nature of this study does not allow for determination of the temporal relationship between sensitization and symptoms. In addition, non-allergic work-related irritation symptoms, which are thought to be more common than allergic symptoms among employees exposed to BAA, may have obscured the relationship

between sensitization and symptoms because the symptoms due to allergy and those due to irritation are similar.

Airborne concentrations of inhalable flour dust, wheat, and α-amylase in our evaluation were higher than those found in both traditional and industrial bakeries in Belgium [Bulat et al., 2004]. GM wheat concentrations were very similar to GM concentrations in PBZ samples of supermarket bread bakers in South Africa, but GM inhalable flour dust and α-amylase concentrations were lower in South African bakeries than in our evaluation [Baatjies et al., 2010]. However, the upper end of the range for all three was much higher in our evaluation. GM inhalable dust concentrations in our evaluation were similar to those in a study of 55 bakeries in the United Kingdom; however, peak exposures were much higher in our evaluation [Elms et al., 2005]. Exposures to BAA were higher in our evaluation than in a study of 65 traditional and 20 industrial bakeries in the Netherlands, but similar to inhalable flour dust and wheat concentrations in seven flour mills [Meijster et al., 2007].

The strong positive correlation in our evaluation between inhalable dust and wheat, and inhalable dust and α-amylase suggest that inhalable dust measurements could be used as a surrogate for the more complicated and expensive, and less widely available, immunological assays. Other studies have documented significant correlation between wheat and inhalable dust [Baatjies et al., 2010], but the correlation between α-amylase and inhalable dust has been variable, with some studies finding significant correlation [Bulat et al., 2004], while others do not [Houba et al., 1997].

A number of recommendations were made to reduce exposure to BAA in this bakery, including using a semi-downdraft ventilation booth while manually weighing and transferring powdered ingredients, and using shorter drums or gravity-fed powder dispensers so employees do not have to reach so far into the drum. The use a pneumatic transfer system equipped with a bag dump station to transfer powdered ingredients from the scaling operation to the mixers was also recommended, as was a central dust collection system for all local exhaust capture hoods, or equipping the local exhaust capture hoods with filters that effectively remove the particulate. Compressed air should not be used to clean surfaces. A high efficiency particulate air filtered vacuum or wet-wash method should be used. Finally, we recommended starting a medical surveillance program for employees who are exposed to flour dust. At a minimum, a medical questionnaire that focuses on skin, mucous membrane, and respiratory symptoms that are work related should be used [Suarthana et al., 2005, 2009].

ACKNOWLEDGMENTS

Industrial hygiene field assistance was provided by Gregory Burr, Kevin L. Dunn, Bradley King, and Duane Hammond. Medical field assistance was provided by Barbara MacKenzie, Deborah Sammons, Christine Toennis, and John Snawder. Analytical support was provided by Barbara MacKenzie; DataChem Laboratories, Clayton Group Services, and the Universiteit Utrecht Institute for Risk Assessment Sciences. Editorial assistance was provided by Ellen Galloway. Health communication assistance was provided by Stefanie Evans. Mention of a product or company name does not constitute endorsement by NIOSH. The content and conclusions of this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. This work was supported in part by an interagency agreement between NIOSH and NIEHS (Y1-ES-0001—Clinical Immunotoxicity).

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