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Adverse respiratory outcomes associated with occupational exposures at a soy processing plant

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Abstract

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This study aimed to characterize the relationship between adverse health outcomes and occupational risk factors among workers at a soy processing plant.

A questionnaire, spirometry, methacholine challenge, immune testing, and air sampling for dust and soy were offered. Prevalence ratios (PRs) of respiratory problems from comparisons with the US adult population were calculated. Soy-specific IgG and IgE among participants and healthcare worker controls were compared. Associations between health outcomes and potential explanatory variables were examined using logistic regression.

One hundred forty-seven (52%) of 281 employees, including 66 (70%) of 94 production workers, participated. PRs were significantly elevated for wheeze, sinusitis, ever-asthma, and current asthma. Participants had significantly higher mean concentrations of soy-specific IgG (97.9 mg/L vs. 1.5 mg/L) and prevalence of soy-specific IgE (21% vs. 4%) than controls. Participants with soy-specific IgE had 3-fold greater odds of current asthma or asthma-like symptoms, and 6-fold greater odds of work-related asthma-like symptoms; the latter additionally was associated with production work and higher peak dust exposures. Airways obstruction was associated with higher peak dust. Work-related sinusitis, nasal allergies, and rash were associated with reported workplace mold exposure.

Asthma and symptoms of asthma, but not other respiratory problems, were associated with immune reactivity to soy.

Key Words

allergy, asthma, immunoglobulin E, immunoglobulin G, occupational, soy

INTRODUCTION

Identifying workplace contributors to asthma is important, as continued exposure can result in chronic pulmonary impairment and can negatively impact productivity, earning capacity, and quality of life [1]. Some soy proteins are recognized allergens, and sensitization to soy has been associated with respiratory disease in some settings. For instance, increases in emergency room visits for asthma following community soy exposures have been well documented [2,3]. However, the relationship between asthma and soy in exposed soy processing workers is less well characterized.

Since the first report of work-related asthma associated with soy in 1934 [4], several studies and case reports have provided conflicting evidence about the role of soy in work-related asthma [5-8]. Cross-sectional investigations in the 1980s and 1990s found that respiratory symptoms and soy-specific immune responses, as measured by skin prick test (SPT) or serum immunoglobulin (Ig) E, were common among soy processing workers [6-8]. Yet none of these studies was able to demonstrate an association between symptoms and soy-specific antibodies. A subsequent investigation of baker's asthma did demonstrate an association between symptoms and soy-specific IgE [9]. However, similar associations were noted for other allergens to which the bakers were exposed, such as wheat and rye flours, complicating the interpretation. Such findings have led some to suggest that soy-specific immune responses may reflect exposure rather than sensitization, and that irritant effects of soy dust (or other concurrent exposures) may be responsible for respiratory symptoms among exposed workers [7,8].

In 2007, a request was received from workers at a Tennessee soy processing plant. The plant receives de-oiled, de-hulled crushed soy flakes by railcar for further processing into soy powder products. Workers in the unloading area empty the soy from railcars into storage bins. The soy flakes are then processed in several flake processing sites of the plant. Following processing, water is added to create a soy slurry. The soy slurry goes to a curd sub-area where soy proteins are extracted, concentrated, and washed. The concentrated soy slurry is sent by high-pressure pumps to be sprayed into the top of a gas-heated spray-drying tower for flash drying. At the bottom of the tower, the soy powder is collected and automatically transferred to the autopackaging sub-area, where it is bagged.

The requesting workers were concerned about asthma and respiratory symptoms that they attributed to workplace exposures, including soy and mold. This study aimed to assess the prevalence of symptoms, diagnoses, and lung function abnormalities among workers at this plant and to understand the contributory role of workplace exposures. In particular, the study sought to better characterize the relationship between immune reactivity to soy and work-related asthma.

METHODS

Medical Survey

The facility's 281 current employees were invited to provide written informed consent to complete a questionnaire and lung function and allergy tests. The 15-minute interviewer-administered questionnaire addressed: respiratory and dermatological symptoms and their work-relatedness; physician-diagnosed asthma and eczema; workplace exposure to mold; smoking history; and employment and demographic information. The respiratory questions were adapted from two validated survey instruments [10,11].

Spirometry testing was conducted according to published guidelines [12]. Test results were interpreted using reference values generated from the Third National Health and Nutrition Examination Survey (NHANES III) [13,14]. Obstruction was defined as a forced expiratory volume in 1 second (FEV_1) to forced vital capacity (FVC) ratio below lower limit of normal [14].

To detect bronchial hyperresponsiveness (BHR), methacholine challenge testing (MCT) was performed [15]. The provocative concentration (PC) of methacholine causing an interpolated 20% decline in FEV_1 (PC_{20}) was determined. BHR was defined as PC_{20} <16.0 mg/ml [15].

SPT was conducted by applying commercially available extracts of soybean food (hereafter, "soy") and 7 environmental allergens, using the GreerPick system (Greer Laboratories, Lenoir, NC, USA). The mean wheal diameter (average of length and width) was determined at 15 minutes. A positive reaction had a mean diameter ≥3 mm larger than the negative control (glycerine) and ≥25% of the positive control (histamine base, 6mg/mL).

Twenty 20 ml of blood from each participant was collected and sera were stored at -80^{o}C. Total IgE, soy-specific IgG (Gf14), and specific IgE to soy (f14), peanut (f13), and storage mite (d71) were determined using ImmunoCAP technology (Phadia AB, Uppsala, Sweden). Total IgE >100 kU/L was considered to be elevated, specific IgG <0.02 mg/L to be undetectable, and specific IgE >0.35 kU/L to be positive. Using these same methods, soy-specific IgG and IgE also were determined in de-identified control sera collected from 50 healthcare workers in a prior investigation [16].

The NIOSH Human Subjects Review Board approved the medical survey.

Environmental Survey

Full-shift, time-weighted average (TWA) personal breathing zone air samples were collected for inhalable dust and soy antigen using Institute of Occupational Medicine Personal Samplers (SKC, Inc., Eighty Four, PA, USA). Samplers were operated at a flow rate of 2 L/min using polytetrafluoroethylene membrane filters with 2 μm pores. For inhalable dust, gravimetric analyses were conducted [17].

For soy antigen, filters were extracted and aliquots were stored at 4^{o}C for immediate use or -80^{o}C for later use. For a reference standard, protein extracts were prepared from bulk pre-processed soy flakes, with protein concentration determined according to the bicinchoninic acid method (Pierce Chemical Co, Rockford, IL, USA). The reference standard was diluted to 1 mg/mL and stored at -80°C. An inhibition enzyme-linked immunosorbent assay (ELISA) modified from Gomes-Olles et al. was used (see Appendix, Online Depository) [18]. The concentration of soy antigen was determined by comparing the optical density at 490 nm of the unknown extracts with that of the reference standard and expressed as mass protein/mL extract.

Personal and area measurements also were made for peak airborne dust using a real-time photometric meter (DataRAM pDR-1000An/1200; Thermo Electron Corporation, Franklin, MA, USA). This sampler responds to particles ranging from 0.1 to 10 μm, corresponding to standard gravimetric measures of respirable and thoracic dust fractions.

Data Analyses

Prevalence ratios (PR) of respiratory symptoms, diagnoses, and obstruction on spirometry were calculated from comparisons with the US adult population prevalence reported in NHANES III using indirect standardization for race, sex, age, and cigarette smoking status [19]. The PR of positive soy-specific IgE was calculated from comparisons with the prevalence observed in the healthcare worker controls. Mean soy-specific IgG levels were compared using Student's t-test.

The outcomes of interest were obstruction, BHR, and the following questionnaire-derived variables: current asthma, asthma-like symptoms, work-related asthma-like symptoms, work-related sinusitis (sinusitis or sinus problems), work-related nasal allergies (including hay fever), work-related rash (skin rash or skin problems), and work-related (usual) cough. Workers with current asthma reported a physician diagnosis of asthma that was still present. Asthma-like symptoms was defined as one or more of the following: wheezing or whistling in the chest in the past 12 months; being woken up with a feeling of tightness in the chest in the past 12 months; an attack of asthma in the past 12 months; or currently taking any medicine for asthma [10]. Work-related symptoms improved away from work.

Potential explanatory variables were derived from questionnaire responses, immune testing, and environmental sampling. Atopy was defined as reported history of nasal allergies and/or eczema. On the basis of 12 current job categories, each represented by ≥5 full-shift TWA personal air samples, participants were assigned to work classifications (production, production support, and non-production), and exposure categories (high, medium, low) for inhalable dust, inhalable soy antigen, and peak dust. Work classifications reflected the proportion of time spent in production areas: all (production), some (production support), or none (non-production). To develop the inhalable dust and soy antigen exposure categories, distributional tertiles of both maximum concentrations and averages (geometric mean [GM], minimum variance unbiased estimator, and arithmetic mean) were examined. Because categorizations were similar regardless of the measure, GM (with geometric standard deviation [GSD]) results are reported only. The peak dust categories were defined by the highest peak during real-time sampling: high if $\geq$10 mg/m^3; medium if $\geq$1 mg/m^3 and $<$10 mg/m^3; and low if $<$1 mg/m^3.

Logistic regression was used to examine associations between outcomes of interest and potential explanatory variables. Odds ratios (OR) and 95% confidence intervals (CI) were estimated using the likelihood ratio test. When more than one explanatory variable was associated with an outcome, stratification and the Cochran-Mantel-Haenszel test were used to assess for confounding.

Associations between measures of immune response to soy and estimates of exposure were explored using logistic and linear regression. IgG values were not normally distributed and were log-transformed for inclusion in the models. Contingency tables were used to examine immunological cross-reactivity to soy and other antigens (birch [20] and peanut [21]) and to explore frequency distributions by exposure categories.

Two-sided $p \leq 0.05$ was considered to be statistically significant. Analyses were conducted with SAS version 9.1 (SAS Institute, Cary, NC, USA).

RESULTS

Medical Survey

Seventy percent (66/94) of production workers, 53% (39/73) of production support workers, and 37% (42/114) of non-production workers completed the questionnaire, for an overall participation rate of 52% (147/281) (Table 1). Most participants had a spirometry test (n=140; 95%), MCT (n=102; 69%), SPT (n=132; 90%), and blood test (n=135; 92%). Table 2 details reported symptoms and diagnoses.

A total of 136 (97%) spirometry tests and 102 (100%) MCTs were interpretable. Fifteen (11%) spirometry tests showed obstruction, similar to the US population prevalence (PR 1.1, 95% CI 0.7-1.9). BHR was identified in 12 (12%) MCTs. For each of the asthma outcomes of interest, participants with the asthma outcome had higher odds of obstruction as follows: current asthma, OR 18.4 (95% CI 5.1-71.2); asthma-like symptoms, OR 2.9 (95% CI 1.0-9.1); and work-related asthma-like symptoms, OR 3.1 (95% CI 0.8-11.9). In addition, participants with the asthma outcome had higher odds of BHR on MCT as follows: current asthma, OR 5.8 (95% CI 0.7-39.3); asthma-like symptoms, OR 3.3 (95% CI 1.0-11.9); and work-related asthma-like symptoms (OR=5.6, 95% CI 1.3-23.4).

Among participants who had SPT, 9 (7%) had a positive reaction to soy (Table 3). Among those who had blood testing, 55 (41%) had elevated total IgE and all had detectable soy-specific IgG, with a mean serum concentration of 97.9 mg/L (range 0.5-2,100 mg/L). In addition, 28 (21%) had soy-specific IgE, 24 (18%) had peanut-specific

IgE, and 14 (10%) had storage mite-specific IgE. Participants with soy-specific IgE were more likely to have a positive SPT to soy (20% vs. 4%; OR 5.9, 95% CI 1.5-25.9). Participants with soy-specific IgE were more likely to have peanut-specific IgE (61% vs. 7%; OR 22.1, 95% CI 7.9-69.1). An association between soy-specific IgE and positive SPT to birch mix did not reach statistical significance (16% vs. 5%; OR 3.6, 95% CI 0.8-14.7).

Environmental Survey

Over 10 full shifts, 178 personal samples were collected for inhalable dust and inhalable soy antigen. Twenty-three personal and 47 area samples also were collected for real-time dust. GM inhalable dust concentrations ranged from 0.17 (GSD 1.3) mg/m^3 for office workers to 1.60 (GSD 3.6) mg/m^3 for autopackaging operators (Figure 1). GM inhalable soy antigen concentrations ranged from 24.3 (GSD 2.5) ng/m^3 for warehouse workers to 25,960 (GSD 4.7) ng/m^3 for curd operators. The highest peak dust exposure from real-time personal sampling was 22.8 mg/m^3 for feed dryer operators and from real-time area sampling was 44.2 mg/m^3 for the feed dryer area. Table 4 details the exposure categories by job category and work classification.

Air samples from production and production support workers had similar GM inhalable dust and soy antigen concentrations, which were higher than those from non-production workers. GM inhalable dust concentrations were 0.77 (GSD 2.9) mg/m^3 for production, 0.60 (GSD 3.2) mg/m^3 for production support, and 0.29 (GSD 2.6) mg/m^3 for non-production. GM inhalable soy antigen concentrations were 2,782.1 (GSD 5.4) ng/m^3 for production, 2991.2 (GSD 15.0) ng/m^3 for production support, and 235.1 (GSD 9.1) ng/m^3 for non-production.

Risk Factor Analyses

Participants had significantly higher prevalence of wheeze (PR 2.1, 95% CI 1.5-2.8), sinusitis (PR 2.0, 95% CI 1.6-2.5), ever-asthma (PR 1.8, 95% CI 1.2-2.8), and current asthma (PR 1.7, 95% CI 1.0-2.9) than the U.S. adult population. Participants had significantly higher prevalence of serum soy-specific IgE than the healthcare worker controls (21% vs. 4%; PR=5.2, 95% CI 1.3-21.0). The mean soy-specific IgG was significantly higher for participants than controls (97.9 mg/L vs. 1.5 mg/L [range <0.02-10]; p<0.001).

Obstruction on spirometry was associated with current work classification of production compared to non-production (15% vs. 2%; OR=7.3, 95% CI 1.3-137), positive SPT to cat hair (27% vs. 7%; OR=5.3, 95% CI 1.0-22.8), and high peak dust compared to low (16% vs. 2%; OR=8.0, 95% CI 1.3-153), but not with smoking status. BHR was not associated with any potential explanatory variables.

All asthma outcomes were significantly associated with soy-specific IgE (Table 5). The association between current asthma and soy-specific IgE remained statistically significant after adjusting for positive SPT to birch (p=0.05), and marginally significant after adjusting for atopy (p=0.07). The association between asthma-like symptoms and soy-specific IgE remained significant after adjusting for atopy (p<0.05). The association between work-related asthma-like symptoms and production remained significant after adjusting for soy-specific IgE ($p<0.05$). The association between work-related asthma-like symptoms and peak dust was marginally significant after adjusting for soy-specific IgE ($p=0.06$).

Soy-specific IgG and inhalable soy antigen exposure categories were significantly associated. Mean soy-specific IgG was higher for workers in the high exposure category (219.3 mg/l) than for those in the medium (45.9 mg/l; $p<0.05$) and low (59.6 mg/l; $p<0.001$) exposure categories. A significant association was not found between serum soy-specific IgE and inhalable soy antigen exposure. The GM inhalable soy antigen concentration was lower in workers with soy-specific IgE than in workers without soy-specific IgE (1595.6 ng/m^3 vs. 4849.2 ng/m^3, $p=0.05$). Both the prevalence of soy-specific IgE ($p<0.01$) and the prevalence of work-related asthma-like symptoms ($p=0.18$) were lowest for workers in the high inhalable soy antigen exposure category (Figure 2).

Table 6 displays characteristics associated with other work-related outcomes, including reported work in areas where mold was seen or smelled. An association between work-related cough and storage mite-specific IgE did not reach statistical significance (21% vs. 6%; OR 4.4, 95% CI 0.9-18.7). None of these work-related outcomes was associated with serum soy-specific IgE.

DISCUSSION

Processed soybeans are the largest source of protein feed and the second largest source of vegetable oil in the world [22]. Over the next decade, global soybean trade is projected to rise 3.5% annually [22]. Thus, understanding the possible occupational risks of soy processing is imperative. Earlier reports were limited by methodological issues such as small sample size and workers' exposure to multiple allergens [5-9].

In this study, workers at a soy processing plant had higher than expected prevalence of self-reported respiratory problems, including asthma. When compared to a control group not known to be occupationally exposed to soy, the soy plant workers studied here had significantly higher levels of soy-specific IgG and a higher prevalence of soy-specific IgE. Given the results of previous investigations [6-8], increased respiratory problems and elevated immune reactivity to soy among soy workers were expected. The unique contribution of the current study lies in its establishing an association between asthma or asthma symptoms and immune reactivity to soy, as measured by the ImmunoCAP assay (but not, notably, by SPT). In particular, workers with serum soy-specific IgE were six times more likely to report symptoms of asthma that improved away from the soy plant than those without soy-specific IgE. These associations were not confounded by atopy or by immunological cross-reactivity to birch or peanut. Furthermore, the observed associations were specific to asthma outcomes, suggesting that they did not reflect a reporting bias among participants with soy-specific IgE.

Several additional workplace factors were important. Compared to non-production workers such as office workers, production workers had nine-fold greater odds of work-related asthma symptoms, and a similar trend was observed for production support workers. The fact that this association was significant even in workers without soy-specific IgE suggests that current work area classification identified an additional risk for asthma symptoms, distinct from soy allergy. It is possible that risk is explained by the effect of peak dust exposure, which was categorized as low for non-production workers and high or medium for others. Unlike TWA measurements, the medium and high peak exposure categories were significantly associated with work-related asthma-like symptoms. This finding indicates a potentially useful role of real-time sampling in workplace investigations [23].

Obstruction on spirometry was associated with several workplace factors, namely current work classification and peak dust exposure category, while BHR was not significantly associated with any of our explanatory variables. The lack of an observed association between obstruction or BHR and immune reactivity to soy may reflect the small numbers of participants with these outcomes. Furthermore, some participants with obstruction may have had other types of chronic obstructive pulmonary disease with causes distinct from those of asthma [24].

While levels of soy-specific IgG reflected inhalable soy antigen exposure categories, such an association was not found between soy-specific IgE and exposure. This discordance may be due to a low threshold for sensitization [25], or tolerance and failure of specific

IgE production due to repeated inhalatory antigen exposure [26,27], but also suggests the presence of a healthy worker effect [28]. Workers with soy-specific IgE may have avoided exposure to higher inhalable soy antigen concentrations through attrition or re-assignment to other areas. Indeed, the fact that only two (7%) of 28 workers with serum soy-specific IgE were in the high inhalable soy antigen exposure category is consistent with a healthy worker effect. In support of this assertion, investigations of wheat allergy in bakery workers have found such a bell-shaped exposure-response curve in cross-sectional studies, but not in longitudinal studies, which are less prone to the healthy worker effect [29]. The inverse relationship between work-related rash and job tenure is further evidence for a healthy worker effect in this population.

There are several limitations. This public health investigation was limited to a single workforce, and participation was lower than desired, although highest among production workers, who would be expected to be at greatest risk of work-related respiratory illness. The small number of workers in sub-groups, such as job and diagnostic categories, may have limited our ability to detect associations. In particular, although stratification allowed us to assess for confounding between health outcomes and explanatory variables, small cells led to imprecision in estimates that precluded conclusions about effect modification. Nonetheless, our 147 participants may constitute the largest group of workers from a soy processing plant to be evaluated for respiratory illness. Indeed, in comparison to previous studies that did not establish an association between asthma outcomes and soy sensitization, our study benefited from sufficient power to detect such associations. Other limitations that should be noted include the emphasis on recent symptoms, current job, and average and peak estimates of exposure. With this approach, contributing factors that occurred in the more distant past or that had a cumulative effect on health outcomes may have been overlooked. However, the observation that soy-specific IgG was associated with the estimates of soy exposure does support this study's methods. Finally, while immune reactivity to soy as measured by the ImmunoCAP assay but not SPT was associated with asthma outcomes, the immunological basis for this distinction was not determined. It is possible that differences in protein content of the two tests contributed [30]. Regardless, it is important to note that while serum soy-specific IgE served as a better indicator of asthma outcomes, some participants without soy-specific IgE had work-related asthma-like symptoms, and current work classification of production was associated with increased risk, independent of immune response to soy. Thus, in the clinical setting, serum soy-specific IgE should not be used to exclude the diagnosis of work-related asthma in soy workers.

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Disclaimer

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Table 1. Characteristics of 147 soy plant workers.

Characteristic	**Value**[a]
Median age, years (range)	46 (19-66)
Male, n (%)	118 (80)
Race	
Black or African-American, n (%)	99 (67)
White, n (%)	47 (32)
Other, n (%)	1 (1)
Smoking status	
Current, n (%)	33 (22)
Former, n (%)	36 (24)
Never, n (%)	78 (53)
Current work classification	
Production, n (%)	66 (45)
Production support, n (%)	39 (27)
Non-production, n (%)	42 (29)
Median tenure at soy plant, years (range)	8 (<1-34)
Worked in area with mold in past 12 months[b], n (%)	57 (39)

[a]Some totals do not sum to 100% due to rounding.

[b]Self-reported.

Table 2. Prevalence of respiratory and dermal symptoms and diagnoses among 147 soy plant workers.

Symptom or diagnosis[a]	**No. (%)**	**Work-related**[b] **No. (%)**
Physician-diagnosed asthma		
Ever	20 (14)	
Current[c]	13 (9)	
Asthma-like symptoms[d]	54 (37)	18 (12)
Wheeze[e]	43 (29)	
Sinusitis[e]	88 (60)	31 (21)
Nasal allergies[f]	49 (33)	12 (8)
Rash[e]	33 (22)	15 (10)
Cough	24 (16)	11 (8)
Physician-diagnosed eczema (ever)[f]	8 (5)	

[a]Self-reported.

[b]Workers with work-related conditions reported that their symptoms improved when away from work.

[c]Workers with current asthma reported a physician diagnosis of asthma and indicated that the asthma was still present.

[d]Workers with asthma-like symptoms reported any one or more of the following: wheezing or whistling in the chest in the past 12 months; being woken up with a feeling of tightness in the chest in the past 12 months; an attack of asthma in the past 12 months; or currently taking any medicine for asthma.

[e]In the past 12 months.

[f]A total of 54 (37%) participants reported a history of nasal allergies and/or eczema and were characterized for analyses as having atopy.

Table 3. Skin prick test positivity among 135 tested soy workers.

Extract	No. (%) positive[a]
Soy	9 (7)
Birch mix	9 (7)
Cat hair	11 (8)
Cockroach mix	14 (11)
10 eastern trees mix	19 (14)
House dust mite mix	22 (17)
Ragweed mix	24 (18)
9 southern grasses mix	40 (30)

[a]A positive reaction was defined as a mean diameter ≥3 mm larger than the negative control (glycerine) and ≥25% of the positive control (histamine) at 15 minutes.

Table 4. Exposure categories for inhalable dust, inhalable soy antigen, and peak dust by job category and work classification.

Job category	Work classification	Exposure Category		
		Dust[a]	Soy antigen[b]	Peak dust[c]
Autopackaging operators	Production	High	Medium	High
Autopackaging assistants	Production	High	Low	High
Curd operators	Production	High	High	Medium
Feed dryer operators	Production	Medium	Medium	High
Production leads	Production	Medium	High	Medium
Spray dryer operators	Production	Low	Medium	Medium
Maintenance workers	Production support	Low	Low	Medium
Sanitation workers	Production support	High	High	High
Unloading operators	Production support	Medium	High	High
Laboratory technicians	Non-production	Medium	Medium	Low
Office workers	Non-production	Low	Low	Low
Warehouse workers	Non-production	Low	Low	Low

[a]Distributional tertiles of inhalable dust concentration: high, 0.75-1.6 mg/m^3; medium, 0.58-0.73 mg/m^3; low, 0.17-0.54 mg/m^3.

[b]Distributional tertiles of inhalable soy antigen concentration: high, 2,635-25,958 ng/m^3; medium, 959-2,297 ng/m^3; low, 24-804 ng/m^3.

[c]Peak dust concentration: high, $\geq$10 mg/m^3; medium, $\geq$1 mg/m^3 and <10 mg/m^3; low, all peaks <1 mg/m^3.

Table 5. Characteristics associated with asthma outcomes in soy plant workers.[a]

Outcome **Characteristic**[c]	**% with outcome**	**Odds Ratio (95% CI)**[b]
Current asthma[d]		
IgE to soy		
Negative[e]	6	1.0
Positive	18	3.7 (1.0-13.2)
Skin reaction to birch mix		
Negative[e]	6	1.0
Positive	33	8.3 (1.5-39.5)
Atopy[f]		
Negative[e]	5	1.0
Positive	15	3.1 (1.0-10.6)
Asthma-like symptoms		
IgE to soy		
Negative[e]	33	1.0
Positive	61	3.2 (1.4-7.7)
Atopy[f]		
Negative[e]	28	1.0
Positive	52	2.8 (1.4-5.6)
Work-related asthma-like symptoms		
IgE to soy		
Negative[e]	7	1.0
Positive	32	5.9 (2.0-17.6)
Current work classification		
Non-production[e]	2	1.0
Production support	13	6.0 (0.9-118)
Production	18	9.1 (1.7-169)
Peak dust exposure category		
Low[e]	2	1.0
Medium	15	7.0 (1.2-131)
High	19	9.4 (1.6-178)

[a]A total of 147 workers participated in the survey; 135 of these were tested for IgE and 132 had skin prick testing. Thus N is less than 147 for some analyses due to missing data for some characteristics.

[b]Unadjusted odds ratios and 95% likelihood ratio confidence intervals.

[c]Asthma outcomes were not associated with other potential explanatory variables in unadjusted analyses: race/ethnicity, gender, age, smoking status, having worked in an area with mold, tenure at the soy plant, history of ever working as a contractor, positive reaction on skin prick test to other tested extracts, elevated total IgE, specific IgG to soy, positive specific IgE to peanut, positive specific IgE to storage mite, inhalable dust exposure category, and inhalable soy antigen exposure category.

[d]Self-reported.

[e]Referent.

[f]Defined as self-reported history of nasal allergies and/or eczema.

Table 6. Characteristics associated with other respiratory and dermal outcomes in soy plant workers.[a]

Outcome **Characteristic**[c]	**% with outcome**	**Odds Ratio (95% CI)**[b]
Work-related sinusitis[d]		
Worked in area with mold[d]		
No[e]	10	1.0
Yes	39	5.7 (2.4-14.1)
Work-related nasal allergies[d]		
Current work area		
Non-production[e]	2	1.0
Production support	15	7.5 (1.2-144)
Production	8	3.4 (0.5-65.6)
Worked in area with mold[d]		
No[e]	4	1.0
Yes	14	3.5 (1.1-13.7)
Skin reaction to birch mix		
Negative[e]	7	1.0
Positive	33	6.3 (1.2-28.7)
Work-related rash		
Worked in area with mold[d]		
No[e]	6	1.0
Yes	18	3.6 (1.2-12.2)
Tertile of tenure at soy plant		
Short[e]	15	1.0
Medium	13	0.9 (0.3-2.7)
Long	2	0.1 (0.01-0.7)
Peak dust exposure category		
Low[e]	5	1.0
Medium	6	1.4 (0.3-10.3)
High	21	5.3 (1.3-36.3)

[a]A total of 147 workers participated in the survey; 135 of these were tested for IgE and 132 had skin prick testing. Thus N is less than 147 for some analyses due to missing data for some characteristics.

[b]Unadjusted odds ratios and 95% likehood ratio confidence intervals.

[c]These outcomes were not associated with other potential explanatory variables in unadjusted analyses: race/ethnicity, gender, age, smoking status, history of ever working as a contractor, positive reaction on skin prick test to other tested extracts, elevated total IgE, soy-specific IgG, soy-specific IgE, peanut- specific IgE, storage mite-specific IgE, inhalable dust exposure category, and inhalable soy antigen exposure category.

[d]Self-reported.

[e]Referent.

Figure Legends

Figure 1. Geometric means and ranges of inhalable soy antigen concentration (squares) and inhalable dust concentration (triangles) for 12 soy plant job categories. Each job category is represented by ≥5 full-shift, time-weighted average personal air samples. P=production, PS=production support, NP=non-production, op=operator, lab tech =laboratory technician, autopack=autopackaging, asst=assistant.

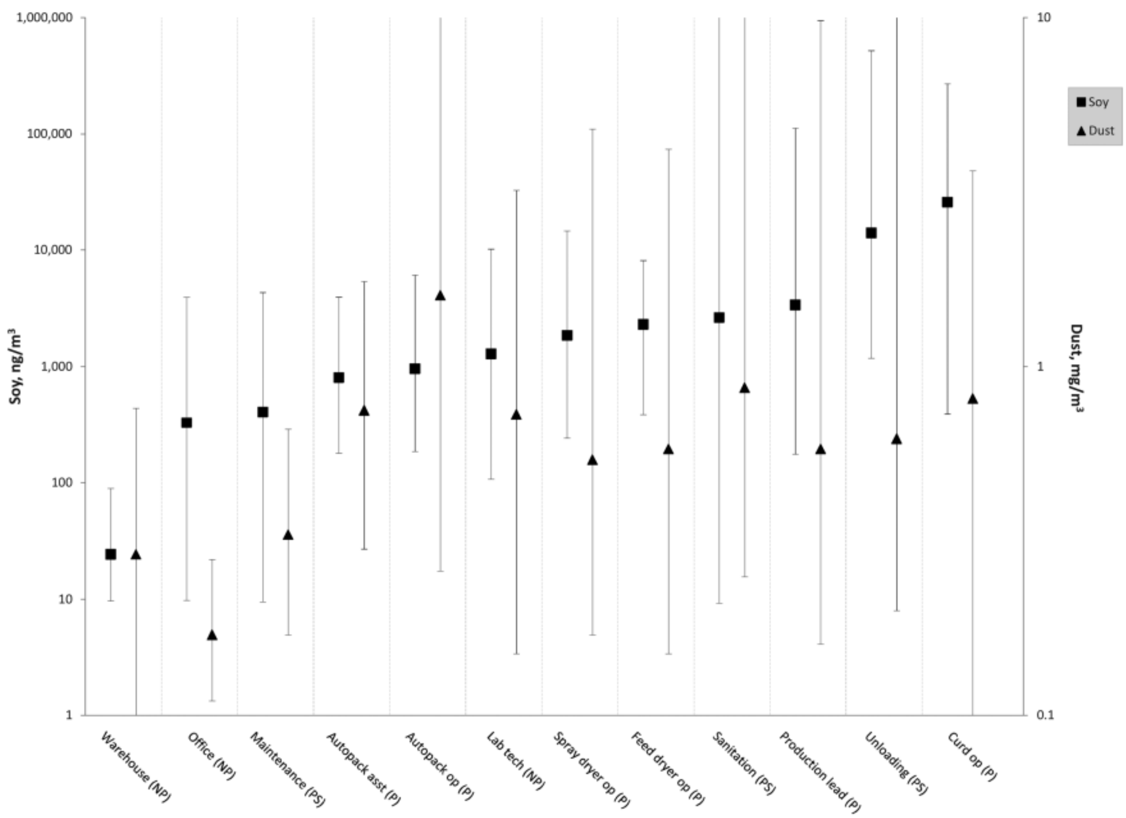
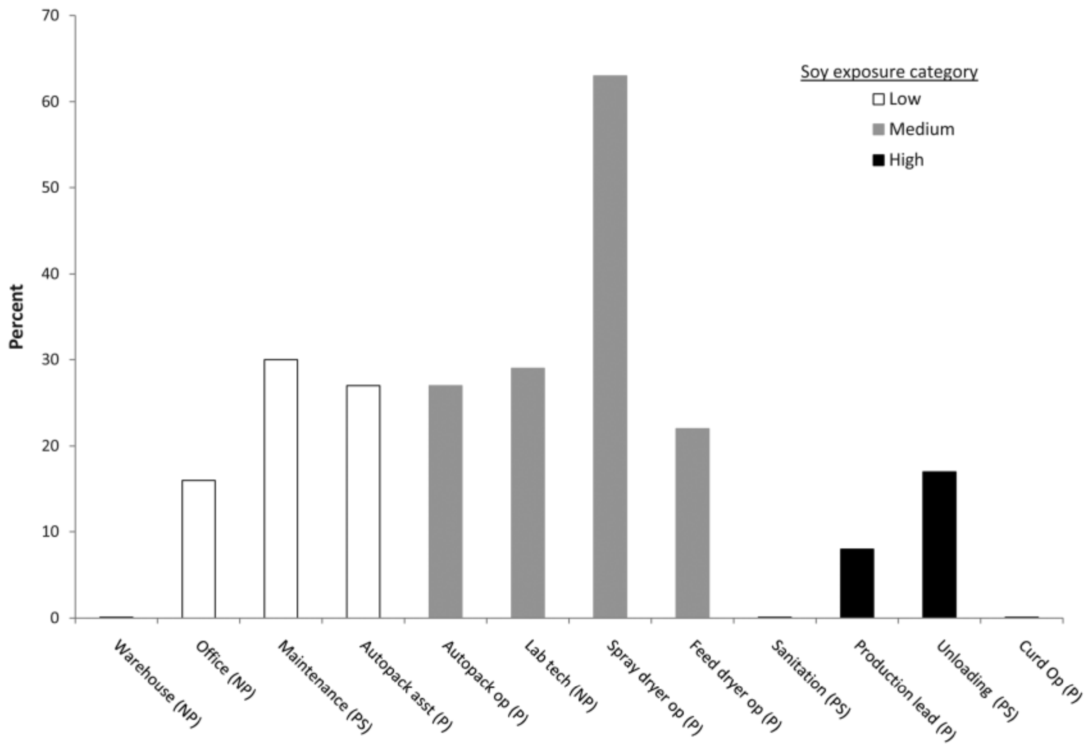


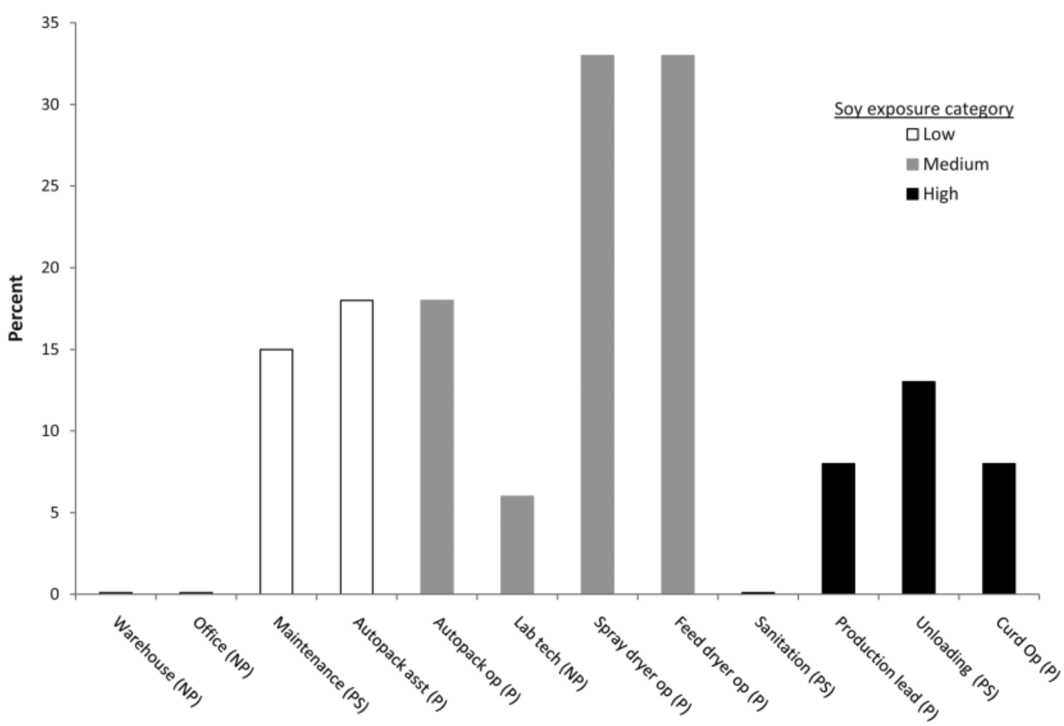
Figure 2. Prevalence of positive IgE to soy (A) and of work-related asthma-like symptoms (B) for 12 soy plant job categories. Job categories are grouped by inhalable soy antigen exposure category, with four jobs in each exposure category (low, medium, high). The prevalence of positive IgE to soy (A) was 21% for workers in the low exposure category, 33% for medium exposure, and 6% for high exposure. The

prevalence of work-related asthma-like symptoms (B) was 9% for workers in the low exposure category, 20% for medium exposure, and 8% for high exposure. P=production, PS=production support, NP=non-production, op=operator, lab tech =laboratory technician, autopack=autopackaging, asst=assistant.

(A)


Soy exposure category
Low
Medium
High
Percent
0
10
20
30
40
50
60
70
Warehouse (NP)
Office (NP)
Maintenance (PS)
Autopack asst (P)
Autopack op (P)
Lab tech (NP)
Spray dryer op (P)
Feed dryer op (P)
Sanitation (PS)
Production lead (P)
Unloading (PS)
Curd Op (P)

(B)


Soy exposure category
Low
Medium
High
Percent
0
5
10
15
20
25
30
35
Warehouse (NP)
Office (NP)
Maintenance (PS)
Autopack asst (P)
Autopack op (P)
Lab tech (NP)
Spray dryer op (P)
Feed dryer op (P)
Sanitation (PS)
Production lead (P)
Unloading (PS)
Curd Op (P)