# Respiratory Health of California Rice Farmers

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**Rice farmers are occupationally exposed to agents that may affect respiratory health, including inorganic dusts and smoke from burning of agricultural waste. To assess respiratory health of this occupational group, we conducted a cross-sectional study, including a self-administered health and work questionnaire, spirometry, and chest radiography among 464 male California rice farmers. Mean age ± SD was 48.3 ± 15.2 yr; mean duration of rice farming was 25.7 ± 14.3 yr. Prevalences for respiratory symptoms were: chronic bronchitis (6.3%), physician-diagnosed asthma (7.1%), and persistent wheeze (8.8%). Chronic cough was reported by 7.1% of respondents and was associated with reported hours per year burning rice stubble. Mean $FEV_1$ and FVC were at expected values. $FEV_1$ was inversely associated with years working in rice storage and use of heated rice dryers. Mean $FEF_{25-75}$ was 93% of expected and was inversely associated with rice storage activities involving unheated rice driers. ILO profusion scores ≥ 1/0 for small irregular opacities were seen in 18 (10.1%) of 178 chest radiographs. Study findings suggest increased asthma prevalence among California rice farmers. Radiologic findings consistent with dust or fiber exposure were increased compared with those of the general population, although no associations with specific farming activities were identified. McCurdy SA, Ferguson TJ, Goldsmith DF, Parker JE, Schenker MB. Respiratory health of California rice farmers.**

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California is the top rice-producing state in the United States and holds 1,575 rice farms comprising more than 400,000 acres (160,000 hectares) (1). Eight northern California counties account for greater than 90% of rice acreage in the state and produce nearly 1.7 million tons of rice annually (2). Rice production is not as labor-intensive as cultivation of row crops, and the industry employs few mirgrant or seasonal farm workers. Farmers perform much of the labor themselves, aided at times by a few employees or family members. Activities such as aerial seeding and pesticide application are usually contracted out.

The rice-growing cycle begins in the spring with field preparation. The field is disked and harrowed, then planed, rolled, and fertilized. Fields are usually seeded by air, followed by flooding and irrigation through the late summer. The crop is harvested in the fall and dried for storage. After harvest, the remaining rice straw is usually burned in the field and disked or plowed under.

Farming entails potential exposures to inorganic and organic dusts and synthetic chemicals that may have adverse effects on respiratory health (3). Rice farmers are also exposed to smoke when burning postharvest stubble. Rice straw contains approximately 12% silica by weight (4), characterized as amorphous or biogenic silica. Biogenic silica liberated as an aerosol during burning may have a fibrous form similar to asbestos fibers and be in the respirable size range (5, 6). This morphologic similarity has led to concern that inhaled biogenic silica fibers may cause pulmonary disease similar to that seen with asbestos: pleural thickening, parenchymal pulmonary fibrosis, and possibly cancer (6). Although morphologic similarity between fibrous biogenic silica and asbestos has been demonstrated (5, 6), most biogenic silica from burned plant material is not fibrous, and its biologic activity has not been thoroughly evaluated.

Crystalline silica aerosolized from soil by farming operations also presents a respiratory health risk for farmers. Crystalline silica dust can cause respiratory disease in miners, sandblasters, and other workers in dusty trades (7). Farm dust may also contain asbestos or other fibrous or nonfibrous silicates that may affect the lung. Case reports suggest that unprotected dust exposures in the agricultural setting may lead to pulmonary fibrosis (8–10).

Despite the potential for respiratory disease associated with rice cultivation, we are aware of no published data describing respiratory health of rice farmers. As an initial effort to characterize respiratory health of this group and identify potentially important occupational exposures, we conducted a cross-sectional study of respiratory symptoms, pulmonary function, and chest radiography among rice farmers in California.

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## METHODS

### Study Population

The study group consisted of 475 rice farmers in eight northern California counties: Butte, Colusa, Glenn, Placer, Sacramento, Sutter, Yolo, and Yuba. Participants were recruited at regular meetings scheduled for rice farmers in the target counties by the University of California, Davis, Cooperative Extension Service. California's rice farmers are concentrated in these counties, and no effort was made to recruit in other counties. A mobile trailer was used at centralized field sites from February through March 1991. Because of practical limitations, we did not attempt to recruit or collect data at individual farms. Participants completed a self-administered questionnaire based on the American Thoracic Society-Division of Lung Disease questionnaire (11) modified to address farming work history and exposures.

### Pulmonary Function Testing

Spirometry was performed according to American Thoracic Society recommendations (12) using a Stead-Wells spirometer connceted to a computer employing pulmonary function software (Pulmo-Screen II/E; S&M Instrument Co., Doylestown, PA).

### Chest Radiography

Chest radiographs were single posterior-anterior views using a Picker radiography apparatus (Picker, Bellwood, IL), operating at 120 kV peak and a source-image distance of 182 cm with automatic exposure control. Films initially received a clinical reading, and participants received the results shortly after their screening. Subsequently, two NIOSH-certified "B" readers reviewed the films independently according to the 1980 International Labour Office (ILO) classification system (13). Standard films were used for comparison. Films were not randomized prior to reading, and readers were not aware of the subjects' exposures or clinical status. Interreader variability was assessed using the kappa statistic (14); intrareader variability was not evaluated. Readings were placed into two categories: profusion scores of $\leqslant$ 0/1 versus $\geqslant$ 1/0 based on the consensus of the two readers. Where the two "B" readers disagreed within this two-category system, a third independent "B" reading was obtained, and the median value of the three readings was adopted as final.

### Statistical Analysis

Data were coded, keypunched, and entered into a VAX 3100 computer. Analysis utilized procedures available in the Statistical Analysis System (SAS Institute, Cary, NC) software package (15). Continuous variables were summarized with mean and standard deviations. Median and percentile distribution scores were used for variables not normally distributed. Initial analysis involved categorization of farming exposure variables and cross-tabulation with health outcomes to look for associations between exposures of interest and health outcomes. These were reexamined after stratifying on age and smoking status. Finally, multiple regression techniques were used to account for the effects of age, smoking status, and occupational exposures. Dichotomous health outcomes and radiography results were analyzed using logistic regression; pulmonary function was analyzed using multiple linear regression. Final models were the results of an all-subsets search; p values were not corrected for multiple comparisons.

Occupational exposures were assessed based on reported years performing specific tasks. These were categorized into approximate tertiles for analysis and included years plowing/tilling freshly burned rice stubble (categorized as < 10, 10–32, and > 32 yr), years performing field preparation (i.e., chiseling, disking, leveling, planing, or harrowing; categorized as < 12, 12–35, and > 35 yr), years applying fertilizer (categorized as < 12, 12–25, and > 25 yr), years applying pesticides (categorized as < 20 and > 20 yr), years harvesting rice (categorized as < 10, 10–33, and > 33 yr), years using a heated rice drier (< 3, 3–16, and > 16 yr), years using a nonheated rice drier (categorized as < 5, 5–20, and > 20 yr), and estimated hours per year (averaged over the preceding 3 yr) spent burning rice stubble (categorized as < 25, 25–70, and > 70 h). Non-rice-farming occupational exposures on at least a half-time basis for 3 mo or more per year were evaluated as dichotomous variables for welding, sandblasting, mining, shipfitting, work with asbestos, foundry work, ceramics or brickmaking, lumber mill work, and fire fighting. Age was analyzed as a continuous variable. Smoking was evaluated as a categorical variable (Never/Former/Current). After controlling for smoking status (Never/Former/Current), no evidence of residual confounding based on cumulative cigarette consumption was found, and final models included only categorical smoking status.

For exploratory purposes, a summary dust exposure index incorporating use of protective equipment, acreage, and reported duration of time performing dusty farm tasks was included. The index was based on the sum of four products, each representing the years performing a specific dusty activity (plowing, ground preparation, harvesting, and rice stubble burning) multiplied by the estimated average annual acreage from the preceding 3 yr. Each of these four products was weighted according to inferred task-specific dust exposure levels based on measurements performed as part of a separate study (data not shown) and the reported percentage time spent in enclosed-cab equipment. Weighting for plowing and ground-preparation activities was 35 for the portion of time spent in open-cab equipment and 3.5 for the portion of time spent in enclosed-cab equipment; weighting for harvesting was 12 for the portion time spent in open-cab equipment and 1.2 for the portion of time spent in enclosed-cab equipment; weighting for rice burning was 1.5. The weighted products were then summed to yield a continuous dust exposure index, which was categorized into approximate tertiles for analysis.

Outcome variables from the questionnaire were chronic cough (coughing on most days of the week for 3 consecutive months or more during the year), chronic bronchitis (phlegm brought up from the chest on most days for at least 3 consecutive months during the year for 2 yr or more), persistent wheeze (wheezing with colds and apart from colds or wheezing most days and nights), history of hay fever, physician-diagnosed asthma, history of "watery eyes" (conjunctivitis), and history of pneumonia. Spirometric outcomes were FVC, $FEV_1$, and midexpiratory flow rate ($FEF_{25-75}$). Expected values were based on prediction equations from Knudson and coworkers (16).

## RESULTS

### Population Characteristics

Four hundred seventy-five subjects participated in the study. Four hundred sixty-four (98%) were men (Table 1), and subsequent analyses were limited to this group. The majority was white, and the mean age was 48.3 yr. Greater than 85% of participants farmed in Colusa, Glenn, Sutter, or Butte Counties. Yolo, Yuba, Placer and Sacramento Counties each contributed less than 5% of participants (Figure 1). Current smokers, ex-smokers, and never-smokers constituted 9.5% (44 of 464), 26.9% (125 of 464), and 63.6% (295 of 464), respectively, of the study group.

TABLE 1

SELECTED DEMOGRAPHIC CHARACTERISTICS OF 464 MALE CALIFORNIA RICE FARMERS*

| Characteristic | (*n*) | (%) |
|---|---|---|
| Male subjects | 464 | 97.7 |
| Ethnicity | | |
| White | 439 | 94.8 |
| Hispanic | 11 | 2.4 |
| Other | 13 | 2.8 |
| County of farm | | |
| Butte | 83 | 18.3 |
| Colusa | 123 | 27.2 |
| Glenn | 99 | 21.9 |
| Placer | 9 | 2.0 |
| Sacramento | 11 | 2.4 |
| Sutter | 102 | 22.5 |
| Yolo | 13 | 2.9 |
| Yuba | 12 | 2.6 |
| Smoking status | | |
| Never smoke | 295 | 63.6 |
| Former smoker | 125 | 26.9 |
| Current smoker | 44 | 9.5 |

* Eleven women originally participated in the study, bringing the total to 475, but the subsequent analyses were limited to the 464 men only. Mean ± SD age was 48.3 ± 15.2.


*Figure 1.* Map of Sacramento Valley rice-growing counties involved in study.

TABLE 2

SELECTED OCCUPATIONAL CHARACTERISTICS OF 464 MALE CALIFORNIA RICE FARMERS

| | | |
|---|---|---|
| Occupational status, n (%) | | |
| Landlord, not operator | 18 | (4.1) |
| Owner/operator | 226 | (51.7) |
| Nonowner operator/contract farmer | 142 | (32.5) |
| Farm employee | 51 | (11.7) |
| Farm size, acres | | |
| Mean ± SD | 551.5 ± 592.3 | |
| Median | 340 | |
| Range | 0–4,500 | |
| Duration of rice farming, yr | | |
| Mean ± SD | 25.7 ± 14.3 | |
| Median | 23 | |
| Range | 0–65 | |
| Performance of selected rice farming tasks, n (%) | | |
| Perform ground preparation | 446 | (96.5) |
| Apply fertilizer | 365 | (78.7) |
| Seed rice crop | 50 | (10.8) |
| Apply pesticide | 229 | (49.4) |
| Plow | 420 | (90.7) |
| Harvest work | 440 | (94.8) |
| Dry rice | 169 | (36.4) |
| Burn rice stubble | 455 | (98.1) |
| Welding | 148 | (32.0) |

Among current smokers, mean ± SD cigarette consumption was 17.5 ± 10.5 cigarettes per day.

Nearly half of the participants were owners/operators (Table 2). Median total acreage farmed during the previous 3 yr was 340 acres (138 hectares). Mean duration of rice farming ± SD was 25.7 ± 14.3 yr. The majority of subjects performed farm production tasks, including harvesting and burning stubble. Previous work with potential exposure to respiratory toxins on at least a half-time basis for 3 mo or more per year was reported for sandblasting by 14 (3.0%) subjects, mining by two (0.4%), shipfitting by three (0.6%), asbestos by four (0.9%), and foundry work by one (0.2%).

### Personal Respiratory Protective Measures

Respirators were worn most of the time or always by 12.7% of respondents during application of pesticides and by 7.4% during rice-drying activities. Burning rice stubble, applying fertilizer, ground-preparation activities, harvesting rice, plowing, and seeding were associated with respirator use by fewer than 5% of respondents. Dust masks worn most of the time or always were reported most frequently for rice drying (31.0%), plowing (24.9%), and pesticide application (19.8%). Other activities were associated with dust-mask use by fewer than 13% of subjects.

### Respiratory Symptoms

Chronic cough was reported by 7.1% of respondents (Table 3). Chronic bronchitis was reported by 6.3% and persistent wheeze by 8.8% of respondents. Hay fever was reported by approximately one quarter of subjects. Age was significantly associated inversely with persistent wheeze: odds ratio (OR) per 10 yr, 0.74; $p < 0.05$. Smoking was an important determinant for many respiratory health outcomes. Current smokers had a 4- to 7-fold increased prevalence for chronic cough, chronic bronchitis, and persistent wheeze. After adjusting for age and smoking, county in which the subject farmed was not significantly associated with study outcomes.

Chronic cough was associated with reported hours per year burning rice stubble (Table 4). When hours per year spent burning stubble was evaluated as a continuous variable, the odds ratio for a person reporting 24 h per year (median value for the group) compared with a subject not performing burning was 1.46 (95% CI = 1.15–1.81). When this activity was considered as a three-level ordinal categorical variable, it achieved borderline statistical significance ($p = 0.05$), and a dose-response effect was evident. The unadjusted prevalence for the lowest exposure category (< 25 h/yr) was 5.2%. Using this category as the reference group, the unadjusted prevalence and adjusted odds ratio for the medium exposure group (25 to 70 h/yr) were 9.5% and 2.15 (95% CI = 0.96–4.79), respectively. The unadjusted prevalence and adjusted odds ratio for the high exposure group (> 70 h/yr) were 11.4% and 3.38 (95% CI = 1.08–10.53), respectively.

Report of having a dusty job on at least a half-time basis for 3 mo or more per year was associated with complaint of watery eyes (OR = 2.47, 95% CI = 1.43–4.27). There was no significant interaction between smoking status and occupational exposure indices.

Employment status was not associated with any outcome except hay fever. Unadjusted prevalence for hay fever among landlords was 11.1%, owners/operators was 29.2%, contract farmers was 29.6%, and employees was 7.8% ($p < 0.01$, chi-square test). Employment status remained significant for this outcome in multivariate models. After adjusting for age, smoking, and employment status, hay fever was increased in subjects reporting work in rice storage and drying activities compared with unexposed subjects (32.5 versus 21.7%; OR = 1.86, 95% CI = 1.20–2.89). No dose-response relationship with years performing these tasks was observed. Similar effects were seen from heated and unheated rice-drying operations.

### Pulmonary Function

Mean performance of the group was above expected for $FEV_1$ (3.93 ± 0.83 L; 102 ± 14% of predicted) and FVC (5.11 ± 0.94 L; 109 ± 14% of predicted). After adjusting for age, height,

TABLE 3

PREVALENCE AND ODDS RATIOS* FOR SMOKING STATUS FOR SELECTED RESPIRATORY SYMPTOMS AMONG 464 MALE CALIFORNIA RICE FARMERS

| Respiratory Symptom | Prevalence in Sample (%) | Symptom Prevalence (%) and Odds Ratio (OR; 95% CI) by Smoking Status | | |
|---|---|---|---|---|
| | | Never Smokers (*n* = 295) | Former Smokers (*n* = 125) | Current Smokers (*n* = 44) |
| Chronic cough | 7.1 | 3.4 (1.0) | 9.6 (2.90†; 1.18–7.14) | 25.0 (9.48‡; 3.74–24.0) |
| Chronic bronchitis | 6.3 | 4.4 (1.0) | 5.6 (1.31; 0.49–3.49) | 20.5 (5.59‡; 2.23–14.0) |
| Persistent wheeze | 8.8 | 6.1 (1.0) | 8.0 (1.80; 0.77–4.19) | 29.6 (6.95‡; 3.06–15.8) |
| Hay fever | 25.7 | 27.8 (1.0) | 23.2 (0.90; 0.54–1.50) | 18.2 (0.58; 0.26–1.31) |
| Physician-diagnosed asthma | 7.1 | 7.8 (1.0) | 5.6 (0.84; 0.34–2.09) | 6.8 (0.88; 0.25–3.09) |
| Watery eyes | 14.9 | 17.0 (1.0) | 11.2 (0.61; 0.32–1.18) | 11.4 (0.63; 0.24–1.67) |
| History of pneumonia | 15.1 | 11.9 (1.0) | 19.2 (1.57; 0.87–2.83) | 25.0 (2.47†; 1.14–5.34) |

* Odds ratios (OR) are simultaneously adjusted for age and smoking. OR for smoking uses the never-smoker group as referent.
† $p < 0.05$.
‡ $p < 0.01$.

and smoking status, $FEV_1$ was inversely associated with reported years working with heated rice dryers (mean decrement = 8.1 ml/yr of exposure; 95% CI = 0.1–16.1 ml). Thus, a rice farmer with 20 yr of exposure would have a predicted reduction of 162 ml for $FEV_1$ compared with a farmer with no exposure. In contrast, the average $FEV_1$ reduction for current smokers compared with never smokers was 178 ml.

Group mean $FEF_{25-75}$ was slightly decreased (3.53 ± 1.41 L/s; 93 ± 46% of predicted). After adjusting for age, height, and smoking status, rice-storage activities involving work with unheated dryers was associated with reduced $FEF_{25-75}$ (mean annual decrement, 13.6 ml/s/yr of exposure; 95% CI = 1.0–26.2 ml/s/yr of exposure). A rice farmer with 20 yr of exposure to rice-storage activities would have a predicted reduction of 272 ml/s for $FEF_{25-75}$ compared with a farmer with no exposure. The reduction in $FEF_{25-75}$ associated with current smoking compared with never smoking was 495 ml/s. There was no interaction between smoking and exposure to rice-storage activities. Analysis of residuals confirmed acceptable model fit. No other occupational exposure indices were significantly associated with pulmonary function test results.

TABLE 4

ASSOCIATION OF RESPIRATORY OUTCOMES WITH OCCUPATIONAL EXPOSURES

| Outcome | Associated Occupational Exposure* |
|---|---|
| Chronic cough | Rice-stubble burning (average hours/year over previous 3 yr) < 25 h: odds ratio (OR) = 1.0; 25 to 70 h: OR = 2.15; > 70 h: OR = 3.38† |
| Chronic bronchitis | None identified |
| Persistent wheeze | None identified |
| Hay fever | Years working in rice drying/storage activities (heated dryers) < 3 yr: OR = 1.0; 3 to 16 yr: OR = 2.57‡; > 16 yr: OR = 1.42 |
| Physician-diagnosed asthma | None identified |
| Watery eyes | Half-time work in dusty job for 3 mo or more per year. OR = 2.47‡ |
| Pneumonia | None identified |
| FVC | None identified |
| $FEV_1$ | Years working with heated rice dryers (mean decrement = 8.1 ml/yr of exposure; 95% CI = 0.1 to 16.1 ml) |
| $FEF_{25-75}$ | Years working in rice drying and storage activities (unheated dryers). Mean decrement, 13.6 ml/s/yr† (95% CI = 1.0 to 26.2 ml/s/yr) |
| Radiographic profusion score ⩾ 1/0 | None identified |

* For all outcomes, the following occupational exposure indices were evaluated for association: plowing/tilling freshly burned rice stubble, field preparation (i.e., chiseling, disking, leveling, planing, or harrowing), applying fertilizer, applying pesticides, harvesting rice, rice storage and drying, and rice-stubble burning. A summary dust exposure index incorporating use of protective equipment, acreage, and reported duration of time performing dusty farm tasks was included.
† p value ⩽ 0.05.
‡ p value ⩽ 0.01.

### Radiography

Chest radiographs from 178 (38%) subjects met technical criteria and were classified by two NIOSH-certified "B" readers. Overexposure accounted for those films not meeting technical criteria for ILO classification. Subjects with acceptable radiographs were younger than the remaining group (45.8 versus 49.8 yr; $p < 0.0001$, Wilcoxon's test) and less likely to report physician-diagnosed asthma (4.0 versus 9.0%; $p < 0.05$, chi-square test). They were comparable to the remaining group with respect to smoking status, years in rice farming, rice acreage, and prevalence of cough, chronic bronchitis, persistent wheezing, and hay fever.

Eighteen subjects (10.1%; 95% CI = 5.4–14.8%) received a final profusion score of ⩾ 1/0. Of these, two had at least one nonfarming potential cause of increased profusion score: one had worked in mining and shipbuilding, and a second reported foundry work. In addition, six subjects (including the two cited above) reported welding work. The prevalence of welding in the group with profusion scores ⩾ 1/0 was similar to that in the entire group (33 versus 32%).

The radiographic pattern was predominantly small irregular opacities in the lung bases. Four subjects (2.2%) had pleural abnormalities. Age was an important determinant of profusion score. The odds ratio for having a profusion score ⩾ 1/0 for a subject 10 yr older than a referent was 2.8 ($p < 0.0001$). Fourteen (83%) chest radiographs with a profusion score ⩾ 1/0 occurred in men 60 yr of age or older; the prevalence of profusion score ⩾ 1/0 in this group was 35% (14 of 40). After adjusting for age, none of the occupational exposure indices was significantly associated with profusion score ⩾ 1/0. Subjects with a profusion score of ⩾ 1/0 did not have reduced spirometric lung function compared with the remaining population after adjusting for age, height, and smoking status.

For 28 subjects (15.6%), the two "B" readers disagreed with respect to whether or not the profusion score was ⩽ 0/1 versus ⩾ 1/0, and a third reading was obtained. Six (21%) of these were ultimately classified as ⩾ 1/0. The kappa statistic for agreement within the dichotomous classification ⩽ 0/1 versus ⩾ 1/0 between the initial two readers was 0.39.

## DISCUSSION

We present the results of a cross-sectional survey of respiratory health among California rice farmers. This investigation was initiated to characterize the respiratory health of rice farmers and explore potential respiratory health effects of exposures related to rice farming, including dusts from soil and rice plant material and smoke from postharvest burning of rice stubble. We have examined several health outcomes for possible relationships with occupational exposures, after accounting for age and smoking status.

Chronic cough was associated in dose-response fashion with reported hours per year burning rice stubble. It is not clear whether this represents a causal association. Exposure to wood smoke is associated with increased respiratory symptoms among wildland firefighters (17). However, the effect appears to be acute in this group. The exposure conditions for rice farmers are also different from those for wildland fire fighters. Rice farmers typically will move out of the plume of smoke, and exposure lasts for a number of hours. In contrast, wildland fire fighters may remain in smoky surroundings for days at a time. However, exposures for rice farmers may have been heavier and of longer duration in previous decades, before regulatory measures restricting burning were introduced.

Prevalence for physician-diagnosed asthma (7.1%) was moderately above that seen in population-based studies. The National Health Interview Survey (NHIS) for 1990 found asthma prevalence of 4.2% among male and female subjects of all ages (18). Asthma prevalence was 2.9% among male NHIS participants 45 to 64 yr of age, a group comparable to the study population reported here. NHIS data show an adjusted prevalence for asthma of 5.2% among white male farmers, yielding a prevalence risk ratio of 1.7 (95% CI = 0.8–2.5) (19). Other studies of agricultural populations in the United States, Canada, and the United Kingdom yield prevalences for asthma between 2.1 and 5.6% (20). A recent study of grain farmers in Saskatchewan, Canada, found a prevalence of 4.9% for asthma among men (21). In addition, persistent wheeze, an outcome that may be related to asthma, was more prevalent among rice farmers than among other groups we have studied. For example, employed Hispanic farm workers in southern California had a prevalence of 2.8% for persistent wheeze (22). A national sample of semiconductor-manufacturing workers demonstrated a prevalence of less than 4% for this outcome (23).

Hay fever, an allergic condition that may be associated with asthma, was reported by approximately one-quarter of respondents, whereas the general population prevalence is approximately 9% (18). However, inland northern California has high seasonal levels of aerosolized pollen, which can cause asthma and other allergic conditions (24). The absence of a local nonfarming control group to assess baseline prevalence of allergic conditions makes interpretation of these findings difficult. The association with rice-storage work is intriguing. Rice storage and drying are dusty operations, and persons engaging in this activity may be exposed to aeroallergens contributing to hay fever. The low prevalence of hay fever among the employee group may represent a "survivor effect." Persons bothered by work-related hay fever may seek other jobs, whereas asymptomatic colleagues are more likely to remain. Employees may have more freedom to seek other employment than do owners-operators or contract farmers.

We also observed a decreased group mean for $FEF_{25-75}$, consistent with mild chronic air flow limitation such as may be seen in asthma. However, $FEF_{25-75}$ has high measurement variability, and it is not clear that the observed reduction represents a clinically significant finding, particularly since the mean $FEV_1$ for the group was above expected. $FEF_{25-75}$ was inversely associated in a dose-response fashion with rice-storage activities involving unheated driers. A similar finding was noted for $FEV_1$, which was inversely associated with reported years working with heated rice dryers. Workers with 20 yr of exposure to rice-storage and -drying activities exhibited reductions in the range seen for current smokers. Reduced airflow may relate to exposure to aeroallergens during rice-storage and rice-drying activities. Studies of respiratory function before and after specific farming tasks, coupled with exposure assessment for dust and aeroallergens, would be helpful in evaluating the findings of increased prevalence of physician-diagnosed asthma, persistent wheeze, and reduced air flow.

Finally, we noted increased prevalence of radiographic profusion scores of ⩾ 1/0 for small irregular opacities. Based on a U.S. "blue-collar" cohort, a prevalence of approximately 0.2% for profusion scores of ⩾ 1/0 in populations with no occupational exposure to fibrogenic dusts would be anticipated (25). However, a Finnish study, using a general population sample of subjects 30 yr of age or older, recently demonstrated age-adjusted prevalence for profusion scores of ⩾ 1/0 for small irregular opacities of 16.5% among men and 10% among women (26). Men with an industrial occupation had a higher age-adjusted prevalence than did men with other or no occupation (20.5 versus 14.6%, $p < 0.001$).

The prevalence of radiographs with profusion scores of ⩾ 1/0 for small irregular opacities is comparable to that seen in employed New York sheet-metal workers, among whom a cross-sectional study demonstrated prevalence of 10.9% for radiographs with profusion ⩾ 1/0 (27). A cross-sectional study of U.S. plumbers and pipefitters demonstrated a prevalence of 7.8% for small irregular opacities of profusion ⩾ 1/0 (28). Construction insulators in British Columbia had a prevalence of 17 to 20% for small irregular opacities of profusion ⩾ 1/0 (29), whereas construction insulators in a large population from eastern North America showed a prevalence of 60% (30). Radiographic studies in these asbestos-exposed occupational groups have generally demonstrated prevalences for pleural abnormalities comparable to or greater than the prevalence of parenchymal abnormalities. In contrast, we found lower prevalence for pleural abnormalities than for parenchymal findings.

Although not all radiographs in our study were technically acceptable for ILO classification, it is unlikely that this materially affected our results. Whether or not a subject had an acceptable radiograph was not influenced by exposure or health status. Subjects with acceptable radiographs were younger than the remaining group and less likely to report physician-diagnosed asthma. Thus, these subjects are likely to have been healthier than the remaining group, resulting in a conservative bias. Even if all subjects with unacceptable radiographs had profusion scores of ⩽ 0/1, the observed prevalence for profusion scores of ⩾ 1/0 in the group as a whole would be approximately 4%, or nearly 20 times that seen in unexposed populations (25).

Radiographic findings we observed among rice farmers may relate to exposure to agricultural dusts containing crystalline silica. Crystalline silica, a component of soil dust, has been associated with respiratory disease in miners, sandblasters, and other dusty trades (7). This is of concern because many rice-farming tasks are associated with soil dust exposures. Although data are lacking for rice farmers, a case report documents silica exposure and pulmonary fibrosis in a farmer with no other known source of silica exposure outside the agricultural work environment (9). However, crystalline silica typically causes radiographic changes in the upper lung fields. The predominant pattern among the rice farmers involved small irregular opacities in the lower lung fields, suggesting silicate or mixed dust exposure, most likely from soil.

Biogenic amorphous silica liberated during burning of rice straw is also a possible source of respiratory exposure to silica. A recent study of California rice farmers documented personal exposures to amorphous silica fibers greater than 5 µm in length up to 1.9 fibers per ml (31). Exposure was highest with field-preparation activities. Area sampling demonstrated concentrations up to 9.9 fibers/ml outside of enclosed cabs. Respirable crystalline silica ranged from 0.02 to 0.09 mg/m$^3$ and was highest for field-preparation activities.

The role these exposures play in causing the observed increase in radiographic abnormalities among rice farmers is not clear. Dust-related pulmonary disease in other occupational settings typically involves chronic exposure over decades, whereas exposures described here usually last several days to several weeks in a given year. Biogenic silica fibers are not morphologically similar to asbestos in that they frequently lack the parallel sides and needlelike form seen for asbestos. Nevertheless, the increased prevalence of radiographic abnormalities consistent with dust exposure suggests an occupational causation, possibly involving crystalline silica or silicates from soil dusts. The radiographic abnormalities are unlikely due to exposures to asbestos because persons with radiographic abnormalities did not have reduced lung volumes, and asbestos typically causes lung volume reductions out of proportion to radiographic findings. In addition, reported work with asbestos or other nonfarm occupational dusts was infrequent.

This study has several important limitations. Because of its cross-sectional design, one cannot demonstrate a temporal connection between exposure and outcome. The study is also subject to selection bias. Persons who developed health problems associated with rice farming or from other causes may not have remained as rice farmers and would not have been available for study (healthy worker phenomenon). In addition, it was not possible to obtain a random sample of California rice farmers, and the study sample consists of volunteers recruited from rice farmer meetings. The study took place amid public concern that burning rice stubble may represent a health hazard for the community at large, ultimately culminating in a legislative measure to limit rice-stubble burning. Persons with respiratory health problems may not have wished to participate in the study to avoid contributing to an impression of ill health among rice farmers. Alternatively, ill persons concerned about their health may have been more likely to participate in order to receive information from spirometry and chest radiography.

We have no way to estimate the magnitude or direction of such selection bias. However, it is most likely that the study participants represented a healthier-than-average group. In particular, prevalence of current smoking was 9.5%, lower than the 12% we observed in a telephone survey of nearly 2,000 California farmers in a separate study (data not presented). Selection of a healthier-than-average sample would result in a conservative bias in our results.

Although this study shows associations between several outcomes and occupational exposures, it is not clear that these represent causal relationships. Some findings may represent Type I errors because of the many exposure-outcome associations we examined. This is less likely for associations exhibiting a dose-response relationship. Reported exposures may be confounders for other unmeasured factors that are causal. Some exposure indices were correlated with age, making it more difficult to detect true underlying associations. Finally, exposure assessment and symptom outcomes were based on questionnaire response. Although outcome questions were standardized, exposure-assessment questions were not, and nonstandardized questions were not supported by previous studies of reliability and validity. Reporting bias may occur if subjects with respiratory symptoms were more likely than healthy subjects to overestimate their exposures.

Despite these limitations, this study represents an important initial step in evaluating the respiratory health of rice farmers. This group appears to enjoy good respiratory health from the standpoint of having low current smoking prevalence and normal group mean values for the major pulmonary function indices $FEV_1$ and FVC. The study also provides evidence of possible occupational lung conditions in rice farmers. Findings suggesting increased asthma in this population include increased prevalences for physician-diagnosed asthma, persistent wheeze, hay fever, and reduced midexpiratory flow rates on spirometry. Occupational dust exposures may increase the risk of asthma in the population. If this association is true and causal, it may relate to as-yet-unidentified substances in aerosols from soil or plant material that are causing allergic sensitization with subsequent asthma.

Profusion scores of ≥ 1/0 may be associated with early pulmonary fibrosis and restrictive lung disease. A decrease in average FVC for the group was not seen, consistent with the fact that the increased profusion scores were of relatively low grade. In addition, we did not detect an association between profusion scores and specific occupational exposures, including the exploratory dust exposure index. However, the marked increase in prevalence of profusion scores of ≥ 1/0 is a new finding, and in the absence of other identifiable causes suggests a common occupational etiology.

Direct measurement of exposures and evaluation of pulmonary function before and after specific tasks, across the season, and over a period of years would help define the occupational determinants of respiratory health in this group. Specific immunologic studies to detect allergic sensitization in rice farmers, in particular in those with respiratory complaints, would help elucidate the nature and cause of the airflow obstruction. Studies to characterize agricultural dusts, including biologic properties, would also be helpful.

On the basis of these data, we recommended that rice farmers reduce whenever possible their respiratory exposures to soil, other dusts, and smoke from burning agricultural waste. Current smoking prevalence appears lower than that of the general population, but smoking cessation should be encouraged because of the presence of occupational exposures that may increase the likelihood of adverse effects on respiratory health. Use of enclosed-cab equipment and, where necessary, NIOSH-approved and properly fitted personal respiratory protective equipment with high efficiency particulate air (HEPA) filters to exclude dust particles should be encouraged.

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