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## SUMMARY

In January 1992, the National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance from the University of Nebraska Medical Center, Department of Internal Medicine, Pulmonary and Critical Care Medicine Section in Omaha, Nebraska. NIOSH was asked to characterize farm worker exposures, as part of an overall assessment of respiratory health effects, during the handling of grain sorghum.

Sampling was conducted at four farms in southeastern Nebraska during grain sorghum-handling operations. Air, bulk grain, and bulk waste material (plant leaves, stems, and dust) samples were collected during harvest at the four farms between October 20-23, 1992. Post-storage air samples were collected at one of the farms the following spring on April 8, 1993, while the grain was being loaded for transport to market. Post-storage bulk samples of the grain materials were also obtained at this farm and at two of the other participant farms.

Area air samples were collected to determine concentrations of respirable dust, total dust, endotoxins, histamine, and viable microorganisms including fungi, and mesophilic, thermophilic, and Gram-negative bacteria. Personal air samples were collected from the breathing zones of workers and analyzed for respirable dust, total dust, endotoxin, and histamine concentrations. Bulk samples were also collected and analyzed for fungi, endotoxins, and histamine.

During harvest, six area concentrations exceeded the NIOSH Recommended Exposure Limit (REL) and the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Value (TLV) of 4 milligrams per cubic meter of air ($mg/m^3$) for total grain dust. Four of those concentrations also exceeded the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for total grain dust of 10 $mg/m^3$. In addition, one personal breathing zone total grain dust concentration exceeded the REL and TLV. No OSHA, NIOSH, or ACGIH occupational exposure standards or recommendations exist for respirable grain dust, fungi, bacteria, endotoxins, or histamine. However, several air samples collected for endotoxins were high by comparison to estimated human thresholds for respiratory response reported in scientific literature.

Most workers were not overexposed to the high concentrations of grain dust found at the grain storage areas at the farms. However, when high area concentrations exist, as in close proximity to grain handling equipment, there is potential for overexposure. This appears to have happened in the case of a worker whose exposure was found to exceed the REL and TLV. The cab enclosures and filtration systems on combines were effective in minimizing exposure of the operators, but if not properly inspected and maintained they can become ineffective.

During area and personal air sampling at grain sorghum farms, concentrations of total grain dust exceeded occupational exposure standards and recommendations. Based on the results of this sampling, it was determined that a potential for worker overexposure to grain dusts exists. Recommendations to minimize worker exposure are included in the Recommendations section of this report.

KEYWORDS: SIC 0119 (Cash Grains - not elsewhere classified), grain sorghum, milo, organic dust toxic syndrome (ODTS), occupational asthma, bronchitis, bacteria, fungi, endotoxins, histamine.

## INTRODUCTION

In January 1992, the National Institute for Occupational Safety and Health (NIOSH) received a request for technical assistance from the University of Nebraska Medical Center, Department of Internal Medicine, Pulmonary and Critical Care Medicine Section in Omaha, Nebraska.  NIOSH was asked to provide the requester with an environmental characterization of farm worker exposures to assist in an assessment of respiratory health effects in farm workers during the handling of grain sorghum.  The University agreed to recruit volunteer farmers in southeastern Nebraska, conduct medical screening of the farmers, and report their findings separately from the environmental findings in this report.

On April 23, 1992, NIOSH investigators conducted a site visit with the requester at a farm in Nebraska to obtain information on typical processes and equipment involved in the handling of grain sorghum. Environmental evaluations were conducted at four farms in southeastern Nebraska on October 20-23, 1992, and April 8, 1993, during grain sorghum handling operations.

## BACKGROUND

Grain sorghum, also known as milo, is a member of the grass family and is grown in the United States mainly for animal feed.  The grain (or seed) color ranges from white to dark reddish brown.  Depending on the growing season, the grain is generally harvested in southeastern Nebraska between September and November.  The typical harvesting operation utilizes a combine machine to cut and gather the top portion of the plant which contains the grain.  The combine separates the grain from the plant, collects the grain in a hopper, and discharges the waste plant material into the field.   When the hopper is full, the combine empties the grain into a transport vehicle (tractor and wagon, truck, etc.) for haulage to a storage site where it is kept until market conditions are favorable for its sale.  At the storage site, the grain is typically transferred to a temporary bin for drying.  Within the bin, the grain can be fan-dried with either ambient or heated air.  Once dried, the grain is transferred to a holding bin, silo, or storage building.  When the farmer is ready to sell the grain, it is generally hauled to a local agricultural cooperative (or co-op) silo from which the collective grain of member farmers is sold.  Transfer of grain between combines, bins, wagons, and trucks is facilitated by such mechanisms as screw augers, bucket elevators, and gravity-fed chutes.

The grain-handling operations vary between farms.  Differences include the size of each operation and the types of bins and equipment used in the handling of the grain.  Manpower also varies.  At some small family farms, the worker who performs the unloading operation may also drive the truck; at other farms separate individuals will perform each of these operations.

# EVALUATION METHODS

Sampling was conducted at four farms in southeastern Nebraska during grain sorghum-handling operations. During the 1992 harvest, air sampling was conducted between October 20-23, 1992, at three of the four farms during the grain gathering operations in the fields and the unloading of the grain at the drying and storage facilities. At the other farm, only the grain gathering operation was evaluated. The farmers handled either red, white, or both varieties of grain sorghum during the sampling. When both varieties were handled, separate samples were collected during the gathering of each. Bulk samples of the grain and waste materials (plant leaves, stems, and dust) were collected from each of the farms. Post-storage air sampling was conducted at one of the same farms the following spring on April 8, 1993, during the loading of grain from storage into a truck for transport to market. Bulk material samples were also collected at this farm, as well as from the storage bins at two of the other participating farms.

Area air samples were collected to determine concentrations of respirable dust, total dust, endotoxins, histamine, and viable microorganisms including fungi, and mesophilic, thermophilic, and Gram-negative bacteria. Details on the air sampling and analytical methods used in this evaluation are included in Table 1. Personal air samples were collected from the breathing zones of workers and analyzed for respirable dust, total dust, endotoxin, and histamine concentrations. At some locations, direct-reading respirable dust measurements were collected via photometry and stored in data-logging equipment. To determine aerodynamic particle size distribution of the dusts, some air samples were collected with impactors. Bulk samples were also collected and analyzed for fungi, endotoxins, and histamine.

# TOXICOLOGY AND EVALUATION CRITERIA

## A. TOXICOLOGY

Overexposure to grain dust has been recognized as a cause of occupational respiratory problems for many years. Common to agricultural dusts, including grain dusts, is the great variability in both dust composition and dust exposure levels. Several different types of respiratory health effects are common to agricultural dust exposures. Potential health problems associated with grain dust exposures can include inflammatory diseases of the eyes, nose, and skin either by direct irritation or by immunological mechanisms. Grain dust exposures have also been associated with respiratory diseases including occupational asthma and rhinitis, bronchitis, hypersensitivity pneumonitis, and organic dust toxic syndrome.

### Occupational Asthma and Rhinitis

Occupational asthma is a reversible obstruction of the airways causally related to the inhalation of agents from the work environment.[1] Asthma is characterized by an increased responsiveness of the airways to various stimuli and manifested by slowing of forced expiration. Asthma is commonly a disease of immunological origin often affecting atopic individuals.[1-5] (Atopy describes a group of common allergic diseases in which there is an inherited tendency to produce immunoglobulin E (IgE) antibodies to allergens on inhaled organic particles.) IgE mediated allergic reactions have been strongly implicated in the pathogenesis of many forms of occupational asthma in conjunction with abnormal autonomic regulation of airway smooth muscle (airway hyper-responsiveness). The interaction of antigen and antibody trigger a series of reactions that result in the release of pharmacological mediators such as histamine, serotonin, eosinophil and neutrophil chemotactic factors, prostaglandins, bradykinins, and others resulting in an asthmatic reaction.[2-4] Two of the primary features of this asthmatic response are bronchial muscle contraction and increased mucus secretion.[2-4] In the etiology of occupational asthma, sensitization to a particular antigen is followed by increased airway responsiveness to that antigen. After sensitization develops, symptoms may result from exposures to even small amounts of that antigen. The clinical manifestations of an asthmatic response are characterized by dyspnea, wheezing, chest tightness, and cough. Asthmatic response can be triggered by a growing list of both natural and synthetic substances including grain products, microorganisms such as fungi, and feed storage mites.[1-4]

Rhinitis is defined as inflammation of the mucous membranes of the nasal cavity and sinuses. Allergic rhinitis, often called hay fever, is characterized clinically by edema of the nasal mucosa with accompanying sneezing, nasal discharge, and nasal obstruction. Occupational rhinitis can be caused by many of the agents in organic dusts that cause asthmatic response. Both occupational rhinitis and asthma can exist concurrently.[1-3]

**Chronic Bronchitis**

Chronic bronchitis is one of the most prevalent respiratory health problems among agricultural workers commonly described among individuals handling grains.[1,6] Chronic bronchitis is defined as chronic sputum production and is associated with chronic cough. It is characterized by hyperplasia and hypertrophy of the mucus secreting cells of the bronchial mucous glands with hyperplasia of the surfaces of large to medium airways and with goblet cell metaplasia in the small airways.[1,4] Resulting morphologic changes include bronchial enlargement and edema of the bronchi. These pathological sequelae result in predominant clinical symptoms including increased mucus secretions, and cough. The presence of dyspnea and hemoptysis (coughing up blood) accompanies more serious, progressive disease. Lung function typically shows an obstructive pattern with a reduction in forced expiratory volume in one second ($FEV_1$) (and often forced vital capacity (FVC)) both over a working shift and with time.[1,3] Exposures to high concentrations of organic dusts, especially those containing grain or cotton materials, has been identified as a risk factor for chronic bronchitis. Cigarette smoking is also identified as a significant factor in the development of bronchitic symptoms.[3,7]

**Hypersensitivity Pneumonitis**

Hypersensitivity pneumonitis is an immunologically mediated pulmonary disease resulting from sensitization and recurrent exposure to a variety of organic components in agricultural dusts. Hypersensitivity pneumonitis is commonly referred to as extrinsic allergic alveolitis, allergic alveolitis, or by other terms specific to the environment causing disease e.g., farmers lung, mushroom workers lung, etc.[1-3] A characteristic immunologic feature is the demonstration of serum precipitating antibodies against environmental antigens. Hypersensitivity pneumonitis is characterized by diffuse mononuclear inflammation of the terminal bronchioles and alveoli. A characteristic disease feature is the presence of large granulomas during acute episodes. Alveolar lavage studies during acute episodes show a predominance of lymphocytes. Repeated insults and persistent chronic inflammation can result in the development of diffuse interstitial fibrosis. Chest radiographs commonly show an interstitial pattern of fibrosis and spirometry is commonly consistent with a restricted disease pattern. Pathogenesis is believed to involve either humoral immunity (immune-complex disease), cellular immunity, or both mechanisms; however, there is uncertainty regarding the exact immune mechanism(s) responsible for clinical disease. The clinical presentation of hypersensitivity pneumonitis depends on the degree and duration of exposure, the immunologic response of the host, and the antigenicity of the dust. Clinically, hypersensitivity pneumonitis can present in both acute and chronic forms. The acute episode is characterized by fever, muscular aches, dry cough, dyspnea, and general malaise occurring approximately 4 to 8 hours after exposure. Symptoms generally reach a peak approximately 8 hours after exposure and subside within 12 to 24 hours. In the chronic form, symptoms are predominately respiratory in nature and include progressive dyspnea and cough. Anorexia and weakness are also possible symptoms. This form of disease is generally seen in individuals chronically exposed to small amounts of antigen. An inherent danger in chronic disease is the progression to irreversible pulmonary fibrosis. A number of etiologic agents have been associated with hypersensitivity pneumonitis. Many agents in organic dusts are capable of causing hypersensitivity pneumonitis. Thermophilic actinomycete bacteria are recognized as an etiologic agent in many cases of hypersensitivity among farmer workers (Farmers Lung) handling hay. Other potential antigens capable of causing disease include fungi and their spores, amoeba, bacteria, avian proteins, organic insecticides, and others.[1-3,6,8]

**Organic Dust Toxic Syndrome**

Organic dust toxic syndrome (ODTS) is a nonallergic, self-limited illness producing acute febrile symptoms following respiratory exposures to high concentrations of organic dusts. Several varieties of toxic syndromes have been described and may comprise descriptions of the same disease, ODTS, in different work environments; among these are pulmonary mycotoxicosis, silo unloaders syndrome, grain fever, and toxin fever. ODTS is characterized by an elevated white blood cell count, and polymorphonuclear leukocytes are typically seen on bronchoalveolar lavage. Lung biopsies have demonstrated acute inflammatory reactions in the lung during episodic disease. Chest radiographs and spirometry are usually normal. Clinical symptoms include fever, muscle and joint pains, headache, and other symptoms resembling influenza. Symptoms generally develop 4 to 6 hours following massive dust exposures. A characteristic aspect of ODTS is the occurrence of disease in clusters with a higher rate of attack among exposed individuals. These symptoms are self-limiting and recovery is common in approximately 24 to 72 hours, although, recurrent episodes can occur and are common on reexposure. Progression to chronic respiratory disease has not been demonstrated. ODTS typically follows massive exposures to organic dusts. Exposures to hays, oats, and wood chips contaminated with large numbers of microorganisms have been associated with the development of disease. Bacterial endotoxin in organic dusts as well as other microbiological agents, are suspected etiologic agents.[1,6-8]

In the assessment of respiratory health problems from agricultural dusts, it is important to consider the multifactorial nature of disease etiology. The nature of the disease outcome is often dependent on both host and environmental factors. This makes the clinical aspects of disease identification and study complex. Overlapping mixed respiratory symptoms complicates disease diagnosis and makes exposure assessment and control more difficult. These factors complicate the evaluation of occupational health problems.[1,7]

## B. EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs)[9], (2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs)[10] and (3) the U.S. Department of Labor (DOL) Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[11] The RELs are usually lower than the PELs because the PELs reflect the feasibility of controlling exposures in various industries where the agents are used, where as RELs are based primarily on concerns relating to the prevention of occupational disease. NIOSH encourages employers to follow the most protective criterion. It should be noted when reviewing this report that employers are legally required to meet those levels specified by an OSHA standard.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8-to-10-hour workday. Some substances have recommended short-term exposure limits (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

OSHA has established a PEL for total grain dust of 10 milligrams of grain dust per cubic meter of air ($mg/m^3$) as a TWA. NIOSH and ACGIH recommend that worker exposure to total grain dust be limited to a TWA of 4 $mg/m^3$. Currently, there are no OSHA, NIOSH, or ACGIH occupational exposure standards or recommendations for respirable grain dust, fungi, bacteria, endotoxins, or histamine. However, the scientific literature contains research describing human threshold exposure limits for endotoxins. The lowest endotoxin exposure reported to cause adverse pulmonary response was measured in exposure studies of subjects sensitive to cotton dusts at 9 nanograms of elutriated endotoxin per cubic meter of air ($ng/m^3$); this concentration is equivalent to approximately 90 endotoxin units per cubic meter of air ($EU/m^3$). Threshold endotoxin exposures among healthy human subjects exposed to cotton dusts are reported by Rylander as approximately 1,000 to 2,000 $EU/m^3$ for an across shift acute pulmonary response (decline in $FEV_1$) and 5,000 to 10,000 $EU/m^3$ for fever.[12-15]

## SAMPLING RESULTS

Results of the sampling at the four farms follow and are also presented in Tables 2 and 3 and Figures 1 and 2.

### Respirable dust

During harvest, detectable area respirable dust concentrations obtained from filter samples ranged from 0.04 to 1.22 $mg/m^3$. Eight of the 16 concentrations were below the minimum detectable concentration (MDC). The MDC for those eight samples ranged from 0.04 $mg/m^3$ for the 302-minute sample to 0.13 $mg/m^3$ for the 89-minute sample. The four personal sample concentrations ranged from 0.04 to 0.22 $mg/m^3$. The two post-storage area sample concentrations were 0.09 and 0.50 $mg/m^3$. Only one personal sample was collected during post-storage sampling, and it measured 0.13 $mg/m^3$.

Figure 1 is a graph of the direct-reading dust measurements obtained during combining of a field. A photometer instrument was placed outside the combine cab, and another was placed inside the enclosed cab containing air-conditioning and air filtration systems. The high peaks on the graph correspond with the movement of the combine in a direction that positioned the air intake downwind of the dust plume generated by the machine. The lower peaks occurred when the combine harvested in the opposite direction with the intake upwind of the plume. Notable on the graph is the time lag between the peaks in the outside and inside concentrations - a result of the time it takes for the concentration to build up in the cab after entering the intake and filter and possibly through leaks in the seals of the doors, windows, and other parts of the cab. More important than the time lag observation is the difference between the inside and outside concentrations. (Note: the scaling of the inside and outside concentration lines on the graph are not the same). This shows the effectiveness of the cab enclosure and filtration system in minimizing occupant exposures to dust.

**Total dust**

Two of the 17 area air concentrations of total dust during harvest were not detectable. The MDC for these samples was about 0.06 mg/m$^3$. The other area sample concentrations ranged from 0.10 to 116.04 mg/m$^3$. The six personal sample concentrations ranged from 0.18 to 6.48 mg/m$^3$. The two post-storage area air samples measured 0.35 and 2.50 mg/m$^3$, and the personal sample yielded a concentration of 1.55 mg/m$^3$

**Aerodynamic Particle Size Distribution**

Data from three sets of impactors were analyzed to determine the size distribution of dust particles. The results were averaged and indicated that approximately 2% of the particles had an aerodynamic diameter of 3.5 micrometers (µm) or less. The remainder of the distribution: 10% at 10 µm or less, 24% at 15 µm or less, 48% at 21 µm or less, 52% greater than 21 µm. This suggests that most of the airborne dusts from these work settings would be deposited in the head or upper airways.[16]

**Endotoxins**

Endotoxin concentrations were obtained from the respirable dust filter samples. Endotoxins were not detectable in half of the 16 area samples collected during harvest. The remainder ranged from 1 to 420 endotoxin units per cubic meter of air (EU/m$^3$). Concentrations were not detectable in two of the personal samples while the other two yielded concentrations of 1 and 7 EU/m$^3$. The two post-storage area concentrations were 1 and 17 EU/m$^3$, and the personal sample measured 2 EU/m$^3$. The MDC for a 302-minute sample was .83 EU/m$^3$, and for a 79-minute sample it was 3.16 EU/m$^3$.

Total endotoxin concentrations obtained from the 17 area total dust samples ranged from 2 to 65,000 EU/m$^3$ during harvest. Post-storage area sampling measured 19 and 69 EU/m$^3$. The samples collected in the breathing zones of six workers ranged from 7 to 329 EU/m$^3$ during harvest, and the sample collected on the worker at the time of post-storage sampling was 83 EU/m$^3$.

For bulk sample analysis, three grab samples were analyzed for endotoxins from each field sample collected. Concentrations of endotoxins on the grab samples from the harvest material ranged from 1 to 1,380 EU/mg, and the post-storage samples concentrations ranged from 3 to 4,210 EU/mg. Apparent in the results is the inconsistency of concentrations between each of the three grab samples collected from many of the field samples. This points out the variability of contamination within the bulk samples. Generally, the trend was for higher concentrations of endotoxins in the bulk dust material samples than the bulk seed samples.

**Histamine**

Total dust samples were also analyzed for histamine content. During harvest, histamine was detectable on only 3 of the 17 area samples and none of the 6 personal samples. The three detectable histamine concentrations were found on the area samples with the highest dust concentrations. The samples measured 23, 336, and 398 picomoles ($10^{-12}$ moles) histamine per cubic meter of air (pmole/$m^3$). Because of the low total dust concentrations measured during post-storage sampling, the filters were not analyzed for histamine. MDCs ranged from 5.37 pmole/$m^3$ for a 310-minute sample to 30.83 pmole/$m^3$ for a 54-minute sample.

Histamine content of bulk material samples collected during harvest ranged from 76 to 2,180 mole/gram. During post-storage sampling, concentrations ranged from 209 to 4,154 pmole/gram.

**Fungi**

Only area concentrations of airborne fungi were measured. Fungi were grown on two types of agar - RBS and DG18. During harvest, 16 samples were collected, and the concentrations of fungi grown on the RBS agar ranged from 1,500 to 5,300,000 colony forming units per cubic meter of air (CFU/$m^3$). Concentrations from the DG18 agar ranged from 1,400 to 4,400,000 CFU/$m^3$. Only the samples collected outside the combine equipment exceeded 1,000,000 CFU/$m^3$. The two post-storage samples collected for fungi yielded concentrations of 1,100 and 4,600 CFU/$m^3$ when grown on the RBS agar, and 4,900 and 9,400 CFU/$m^3$ on the DG18 agar.

As shown in Table 3, bulk materials collected during the harvest sampling contained between 34,000 and 4,600,000 CFU of fungi per gram of material (CFU/g) when grown on RBS agar and between 34,000 and 6,900,000 CFU/g when grown on DG18 agar. The bulk waste material (dust, stems, leaves, etc from the plants) contained more fungi than the bulk seed samples. This would be expected because these parts of the plant are more exposed to the weather than the seeds. Bulk materials collected during the post-storage sampling contained between 59,000 and 16,000,000 CFU/g when grown on RBS agar. A similar range was found when fungi were grown on the DG18 agar.

All the fungi samples were also analyzed for identification of predominant organisms. Yeasts and fungal organisms of the *Cladosporium* genus were the most common organisms found in the air and bulk samples.

**Bacteria**

Area air concentrations of viable bacteria were measured at each of the farms. During harvest, concentrations of mesophilic bacteria in the 16 sampled locations ranged between 800 and 980,000,000 CFU/$m^3$. Thermophilic bacteria were detected in one of four samples at each of three of the farms at concentrations of 3,500, 12,000, and 22,000 CFU/$m^3$. Gram-negative bacteria were measured in only one sample at a concentration of 660,000,000 CFU/$m^3$. During post-storage sampling, mesophilic bacteria were measured in each of the two samples at 2,500 and 74,000 CFU/$m^3$. Neither thermophilic nor Gram-negative bacteria were detected in those samples. The MDC's for the samples ranged from 200 CFU/$m^3$ for the 317-minute sample to 1,200 CFU/$m^3$ for the 54-minute sample.

Mesophilic bacteria of the *Corynebacterium* genus were the most predominant in the air samples collected during harvest.  Thermophilic bacteria of the *Thermoactinomyces* genus were present in some of the samples, and Gram-negative bacteria (*Pseudomonas vesicularis*) was identified in one sample.  At the time of the post-storage sampling, only mesophilic bacteria, especially *Staphylococcus auricularis,* were found in both air samples.

## DISCUSSION AND CONCLUSIONS

OSHA has established a PEL for total grain dust of 10 mg/m$^3$.  NIOSH and ACGIH recommend that worker exposure to total grain dust be limited to 4 mg/m$^3$.   During harvest sampling, the two area total dust samples collected outside the combine measured the highest concentrations -- both exceeded 100 mg/m$^3$.  These and four other area total dust sample concentrations collected at the storage sites (35.02, 22.15, 5.33, and 4.04 mg/m$^3$) exceeded the REL and TLV.  The two outside combine and two highest storage site sample concentrations also exceeded the OSHA PEL.  Two other area sample concentrations measured at the storage sites (both 3.81 mg/m$^3$) approached the REL and TLV.

Of the six personal total grain dust sample concentrations, only one sample (6.48 mg/m$^3$) exceeded the NIOSH REL and ACGIH TLV.  This sample was collected on a worker who operated a combine but also shoveled grain inside a storage bin.  Because the area samples associated with this worker indicated a low concentration inside the combine (which was enclosed and air-conditioned) and a higher concentration inside the bin, it is likely that the majority of the exposure was obtained during his shoveling operation.

As stated previously, there are no OSHA, NIOSH, or ACGIH occupational exposure standards or recommendations for respirable grain dust, fungi, bacteria, endotoxins, or histamine.  However, the lowest endotoxin exposure reported in scientific literature to cause adverse pulmonary response in subjects sensitive to cotton dusts was 90 endotoxin units per cubic meter of air (EU/m$^3$).  Threshold endotoxin exposures among healthy human subjects exposed to cotton dusts are reported by Rylander as approximately 1,000 to 2,000 EU/m$^3$ for an across shift acute  pulmonary  response (decline in $FEV_1$) and 5,000 to 10,000 EU/m$^3$ for fever.[12-15]  Eight of the area total dust samples analyzed for endotoxins indicated concentrations in excess of 90 EU/m$^3$.  Three exceeded 1,000 EU/m$^3$, and two of those (the outside combine samples) exceeded 10,000 EU/m$^3$.  The highest personal sample concentration was 329 EU/m$^3$, and it was the only sample to exceed 90 EU/m$^3$.  That sample was collected on the same person with overexposure to total grain dust.

As was found in area sampling for total grain dust and endotoxins, the two samples collected outside the combine measured the highest concentrations of each analyte (except for one thermophilic bacteria sample).  The contaminant concentrations of the samples collected simultaneously inside the cab were either considerably lower than the outside samples or not detectable.  Contaminant concentrations inside the cabs of all the other combines were also low.  This indicates that the air-conditioned enclosure was effective in protecting the workers from the dusty environment created by the combine.  It should be noted that any defects in this enclosure (such as leaks in the seals, malfunctioning air-conditioner, or overloaded, defective, or improperly sized filters) could render the enclosure ineffective.

Workers were not exposed to the high concentrations of dust created by the combines. However, area dust concentrations that exceeded the PEL, REL, and TLV were also measured at the grain handling equipment at the storage sites. As observed during the sampling at these sites, workers generally spent only brief periods of time performing tasks in any one area at these sites. This does not exclude the potential for overexposure as was seen in the personal sampling of the farmer who likely experienced low exposure while he operated his combine but high exposure later that day when he shoveled grain inside a storage bin. Overexposure could also occur at other times or at other farms where conditions could be different from those observed during this sampling. In addition, as previously noted for occupational asthma and hypersensitivity pneumonitis, even exposures to small amounts of an antigen may result in symptoms after sensitization develops.

An operation that takes place at these farms that was not sampled during this evaluation is the cleaning of the storage bins prior to filling them with the current season's harvest. It was described as an operation in which grain and dust is swept from the ledges and floor of the bins. This operation could potentially produce high concentrations of airborne dust inside the bin.

While sampling at the farms, the investigators experienced skin and eye irritation similar to the itching and prickling sensations encountered when working with fiberglass insulation material. Workers claimed this irritation was typical when handling the grain. Microscopic analysis of settled dust revealed a predominance of needle-like particles (trichomes) as shown in Figure 2. Trichomes are highly variable appendages of the epidermis of plants, including glandular (or secretory) and nonglandular hairs, scales, papillae, and absorbing hairs of roots.(17) The function of many of the trichomes is obscure, but some studies have suggested they can insulate the plant from excessive heat, remove toxic salts, or provide defense against some insects. Secretory trichomes may participate in chemical defense for the plant. The secretions from trichomes can include protective oils, enzymes, salts, and other unknown substances. The nature of the trichomes found in this evaluation were not investigated beyond the microscopic analyses. However, the needle-like shape of the trichomes found in the dusts during this evaluation suggests they could play a role as physical irritants of the skin and eyes and, because they become airborne, possibly of the upper respiratory tract. The smaller round particles shown in the lower photograph of Figure 2 are predominantly starch grains.

Most workers did not wear respirators when handling grain at the farms.

## RECOMMENDATIONS

Based on the industrial hygiene characterization at the grain sorghum farms, the following recommendations are provided as general guidelines to aid in the reduction of workplace exposure and respiratory health problems in the production of grain sorghum:

1. Workers should be knowledgeable of the respiratory health hazards posed by overexposure to organic dusts and aware of symptoms that can accompany overexposure. A very useful publication that deals with this subject is NIOSH Publication 94-102 "*Request for Assistance in Preventing Organic Dust Toxic Syndrome*."(18) Recent NIOSH publications can be obtained by calling 800-356-4674.

2. Care should be taken to ensure that the harvest and storage of agricultural products is done in a manner to minimize spoilage and microbiological contamination.

3. Workers involved in handling grain should be protected from overexposure through the use of engineering controls such as local exhaust ventilation. In instances where the work activity is not amenable to control by engineering methods, or during interim periods of process change (e.g., ventilation system installation), appropriate respiratory protection should be used to prevent worker overexposure.

4. When respiratory protection is used, care should be taken in selecting an appropriate type of respirator. The NIOSH recommendation is for a minimum level of respiratory protection equal to the disposable N95 filter respirator certified by NIOSH (42 CFR 84). High efficiency particulate filter (HEPA) respirators certified by MSHA/NIOSH under 30 CFR 11 or other N, P, or R filter respirators certified by NIOSH under 42 CFR 84 could also be selected. The respirators selected should have an assigned protection factor (APF) sufficient to protect workers from the airborne contaminant concentrations present in the work setting. Different levels of respiratory protection may be required for high exposure tasks such as the sweeping of dusts during cleaning operations. More detailed information on the selection and use of respirators can be found in NIOSH Publication 96-101 *"Selection and Use of Particulate Respirators Certified under the Provisions 42 CFR Part 84."*

5. Combine cab enclosures, air-conditioners, and filters should be inspected and maintained regularly to ensure their effectiveness in minimizing occupant exposure to dust.

6. Workers should wear appropriate personal protective equipment (PPE) to minimize skin and eye contact with grain materials.

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Table 1
Air Sampling and Analytical Methods

University of Nebraska Medical Center
Omaha, Nebraska
HETA 92-0122
October 20-23, 1992 and April 8, 1993

| Analyte | Sampling Media | Air Flow | Analytical Method |
|---|---|---|---|
| Respirable Dust | 37-mm diameter, 5-µm pore, tared polyvinyl chloride (PVC) filter in 2-piece cassette with 10-mm nylon cyclone as a prefilter | 1.7 lpm | Gravimetric via NIOSH Method 0600[19] |
| | Photometer | None (passive) | Direct reading via photometry. Data collected in data logger |
| Total Dust | 25-mm diameter, 5-µm pore, tared PVC filter in 3-piece (open-faced) cassette | 2 lpm | Gravimetric via NIOSH Method 0500[19] |
| Viable Fungi | 37-mm diameter, .4-µm pore, plain polycarbonate filter in 3-piece (open-faced) cassette | 2 lpm | Identification of fungi by dilution plating on nutrient agar (DG18 and RBS), incubation, and colony counts[20-23] |
| Viable Bacteria<br>-mesophilic count<br>-thermophilic count<br>-Gram-negative count<br>(with ranking of species by quantity) | 37-mm diameter, .4-µm pore, plain polycarbonate filter in 3-piece (open-faced) cassette | 1 lpm | Identification of bacteria by dilution plating on nutrient agar (trypticase soy), incubation, and colony counts[20-24] |
| Endotoxins | Analyses from filters used in gravimetric respirable and total dust samples | | Lymulus amebocyte lysate (LAL) test[25] |
| Histamine | Analyses from filters used in gravimetric total dust samples | | Radioimmunoassay[26] |
| Particle Size Distribution | 37-mm diameter glass fiber filters in multistage cassette impactor[27] | 2 lpm | Gravimetric |

mm = millimeter
µm = micrometer
lpm = liters per minute