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Occupational exposure to particulate matter from three agricultural crops in California

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ABSTRACT

Agricultural work is a major contributor to California's and the nation's economy and employs a large number of workers. However, agricultural work can have numerous risks, such as exposure to elevated levels of particulate matter (PM) and other airborne pollutants with potential adverse health effects. To determine the magnitude of occupational exposures, PM levels were assessed for 89 workers from three major crops in California; almonds, melons and tomatoes. Personal samples were collected for $PM_{2.5}$ and inhalable PM using personal sampling equipment. Geometric mean concentrations from personal exposure for workers in almonds (inhalable PM = 4368 $\mu g/m^3$, $PM_{2.5}$ = 122 $\mu g/m^3$, N = 5), tomatoes (inhalable PM = 1410 $\mu g/m^3$, $PM_{2.5}$ = 12 $\mu g/m^3$, N = 33), and melons (inhalable PM = 1118 $\mu g/m^3$, $PM_{2.5}$ = 19 $\mu g/m^3$, N = 51) showed high PM exposure when working with these three crops. Large exposure differences by crop were more common than by task (i.e. harvesting, packing and weeding) among the three crops studied. This is the largest study of agricultural workers engaged in hand harvesting, a significant employer of farm labor, and relatively high levels of exposure to PM were measured.

Introduction

In 2007, one out of every ten farms in the United States (US) was located in California (CDFA, 2008-09), growing 50% of the entire US fruit, vegetable and nut production. California is also the sole supplier of certain crops, such as almonds, for which California contributes 99% of the total for the nation (CDFA, 2008-09). As such, agriculture is a large part of California's economy and employs a great number of workers.

Migrant farm workers provide the majority of the workforce for California's labor-intensive agricultural sector. Farm workers are often exposed to high levels of particulate matter (PM) and are susceptible to a wide variety of worker related respiratory ailments. California agriculture workers have shown both decreased respiratory functions and increased respiratory symptoms, including chronic cough and persistent wheeze, in addition to increased mortality rates from chronic pulmonary disease compared to the general population (Schenker et al., 2005; Singleton, 1989; Stubbs et al., 1984). Farm workers are also susceptible to organic dust toxic syndrome (ODTS), asthma like symptoms, and pneumoconiosis (Faria et al., 2006; Linaker and Smedley, 2002; Schenker et al., 1998).

The type, concentration and duration of exposure to airborne pollutants depend on the type of work environment, the nature of the work being performed and the type of agricultural operation (Preller et al., 1995; Schenker et al., 1998; Schierl et al., 2007). Migrant farm workers in the California Central Valley have exposures different from most traditional farm work, as it is very dry and dusty, with less organic content in the dust (Lee et al., 2004; Nieuwenhuijsen et al., 1999; Schenker et al., 2009) In addition, elevated exposures to PM are anticipated for some agriculture workers due to the harvesting process used. Different crop harvesting methods can lead to different levels of PM re-suspension and, consequently, occupational exposure. There is limited data reported for farm workers working with the types of food crops grown in this region relative to the large amount of agriculture work performed in California.

This study was part of a larger health study, the Mexican Immigration to California: Agricultural Safety and Acculturation (MICASA) study, looking at farm worker families within the town of Mendota in the Central Valley (Stoecklin-Marois et al., 2011). A goal of this epidemiology study was to classify participants, based on crop and task, in order to look for a relationship between classification groups and exposure.

In this study, we (i) quantify occupational exposure concentrations of two particle size fractions, $PM_{2.5}$ and inhalable PM, for three crops grown in California, (ii) evaluate what impact job task

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performed by the workers and crop type can have on PM concentrations; and (iii) evaluate if perceived occupational exposure is a valid predictor of true exposure.

Materials and methods

Overview

The study was performed in the southern portion of California's Central Valley from May to October 2009 and involved farm workers working with three distinct agricultural crops – tomatoes, melons and almonds – on three different farms.

Study participants were selected from farm workers who were working in close proximity to the crops on the sampling day. All workers willing to participate in the study were included, with no specified exclusion criteria. Tasks considered as contributing to particulate exposure were harvesting (hand and machine), packing and sorting, and weeding/sweeping, further defined in Table 1. Personal samplers were placed on participating workers for approximately 8 h. Questionnaires were also administered in which workers were asked to self report on PM levels while working. Specifically, workers were asked to rate both the amount of dust generated while working in a specific crop and task and the amount of dust generated during their entire work day, during the day that sampling occurred, on a scale of 0–10, with 0 indicating no dust at all and 10 indicating dust that severely restricted their view. Workers who worked in more than one task and/or one crop were excluded from all analysis. The study was approved and conducted under the rules and protocols of the UC Davis Institutional Review Board.

Sampling

A GK2.05SH (KTL) cyclone sampler (BGI Inc., Waltham, MA) with a cut point of 2.5 μm and an air flow rate of 3.5 L/min was used to collect $PM_{2.5}$. This sampler has been shown to have good agreement with the PQ200 (BGI Inc.) Federal Reference Method $PM_{2.5}$ sampler (Majestic et al., 2008; Yanosky and MacIntosh, 2001). We used Teflon 37 mm Millipore filters with a pore size of 0.45 μm (Fisher Scientific, FHLP03700, Waltham, MA). A SKC button sampler (SKC, Inc. 225–360, Eighty Four, PA) with a curved multi-orificed inlet with a cut point of100 microns at an air flow rate of 4.0 L/min was used to collect inhalable PM. Each button sampler was fitted with a Teflon 25 mm, Millipore PTFE filter with a pore size of 3.0 μm (Fisher Scientific, FSLW02500). Tygon tubing connected the samplers to a Swagelok (Swagelok, Solon, OH) needle valve for flow adjustment. The samplers were attached to a high flow Leland Legacy personal sampling pump (SKC, Inc.) and placed in a backpack with samplers placed at worker breathing level. Prior to the pumps being connected to the sampling assembly, they were warmed up for 15–20 min. Air flow was measured pre and post sampling using a Defender-series (Bios International, Butler, NJ) electronic piston volumetric gas flow meter. Samples that were more than 10% of specified flow where excluded from analysis as well as samples that suffered due to equipment malfunction.

Gravimetric analysis

Filters were weighed using a Cahn-35 microbalance (Thermo Fisher Scientific Inc., Pittsburgh, PA). The filters were equilibrated in a class 100 cleanroom with temperature and humidity controlled to 70 ± 5 °F (∼21 ± 3 °C), 50 ± 5% RH for 24–48 h prior to being weighed at least two times. The microbalance was calibrated at the beginning of each weighing session for accuracy, and a quality check was performed after every tenth filter to account for fluctuation. Any shift of ±0.002 mg resulted in reweighing the ten previous filters.

Data analysis

Descriptive and graphical statistical methods were applied to describe and compare the task- and crop-specific exposure concentrations. Potential outliers are those falling more than 1.5 inter-quartile ranges above the 75th (or below the 25th) quartile in boxplots (Tukey, 1977). Outliers were not excluded from data analyses. The unit of analysis for our data was the daily exposure concentration.

Spearman correlation coefficients were calculated between regional $PM_{2.5}$ concentrations and $PM_{2.5}$ concentrations collected from personal sampling equipment of the workers. The regional $PM_{2.5}$ concentrations were those reported by the California Air Resources monitoring network, a collection of Federal reference method approved $PM_{2.5}$ samplers located throughout California. The concentrations reported from those samplers in closest proximity to each farm were used to determine the correlation between regional $PM_{2.5}$ and $PM_{2.5}$ concentrations from personal samplers. The farms included in this study were all located within the central valley of California, which is a single air shed, and within 30 to 50 miles of the monitoring station.

Spearman correlation coefficients were calculated between perceived or "self reported" exposures determined at the end of the work shift and actual exposures as collected using personal sampling equipment.

Mixed-effects (multilevel) regression models were used to assess whether log-transformed exposure concentration outcomes varied by task for workers who harvested melon or tomatoes (almonds were excluded due to low N). Regression models included harvesting, packing/sorting, and weeding/sweeping. All mixed effects models were estimated using the restricted maximum likelihood regression (REML) approach.

Statistical analysis for all analyses was performed using SAS version 9.2 (SAS Institute, USA).

Results

Exposure concentrations

Data from 89 farm workers was examined in this study. Geometric mean levels of personal exposure were higher for almond workers (inhalable PM = 4368 μg/m^3, (SD = 4.1 μg/m^3); $PM_{2.5}$ = 122 μg/m^3, (SD = 7.8 μg/m^3); N = 5) compared to melon (inhalable PM = 1118 μg/m^3, (SD = 1.6 μg/m^3); $PM_{2.5}$ = 19 μg/m^3, (SD = 2.6 μg/m^3); N = 51) and tomato workers (inhalable PM = 1410 μg/m^3, (SD = 2.1 μg/m^3); $PM_{2.5}$ = 12 μg/m^3, (SD = 2.9 μg/m^3); N = 33) (Fig. 1a–d). In contrast, melon and tomato workers had similar exposure concentrations. We note that reported results for almonds should be interpreted cautiously due to the small sample size.

Only melon and tomato workers could be evaluated for exposure by task because of the large worker sample sizes for these crops. Occupational exposure distributions varied considerably between workers performing the same task, with no significant difference between melon and tomato workers across tasks (Fig. 2a and b). The geometric mean concentration was slightly lower for packing/sorting: packing/sorting (inhalable PM = 1126 μg/m^3, (SD = 2.6 μg/m^3); $PM_{2.5}$ = 17 μg/m^3, (SD = 2.5 μg/m^3); N = 12) versus harvesting (inhalable PM = 1362 μg/m^3, (SD = 1.6 μg/m^3); $PM_{2.5}$ = 22 μg/m^3, (SD = 2.8 μg/m^3); N = 32) and weeding/sweeping (inhalable PM = 1315 μg/m^3, (SD = 1.8 μg/m^3); $PM_{2.5}$ = 12 μg/m^3, (SD = 2.9 μg/m^3); N = 29).

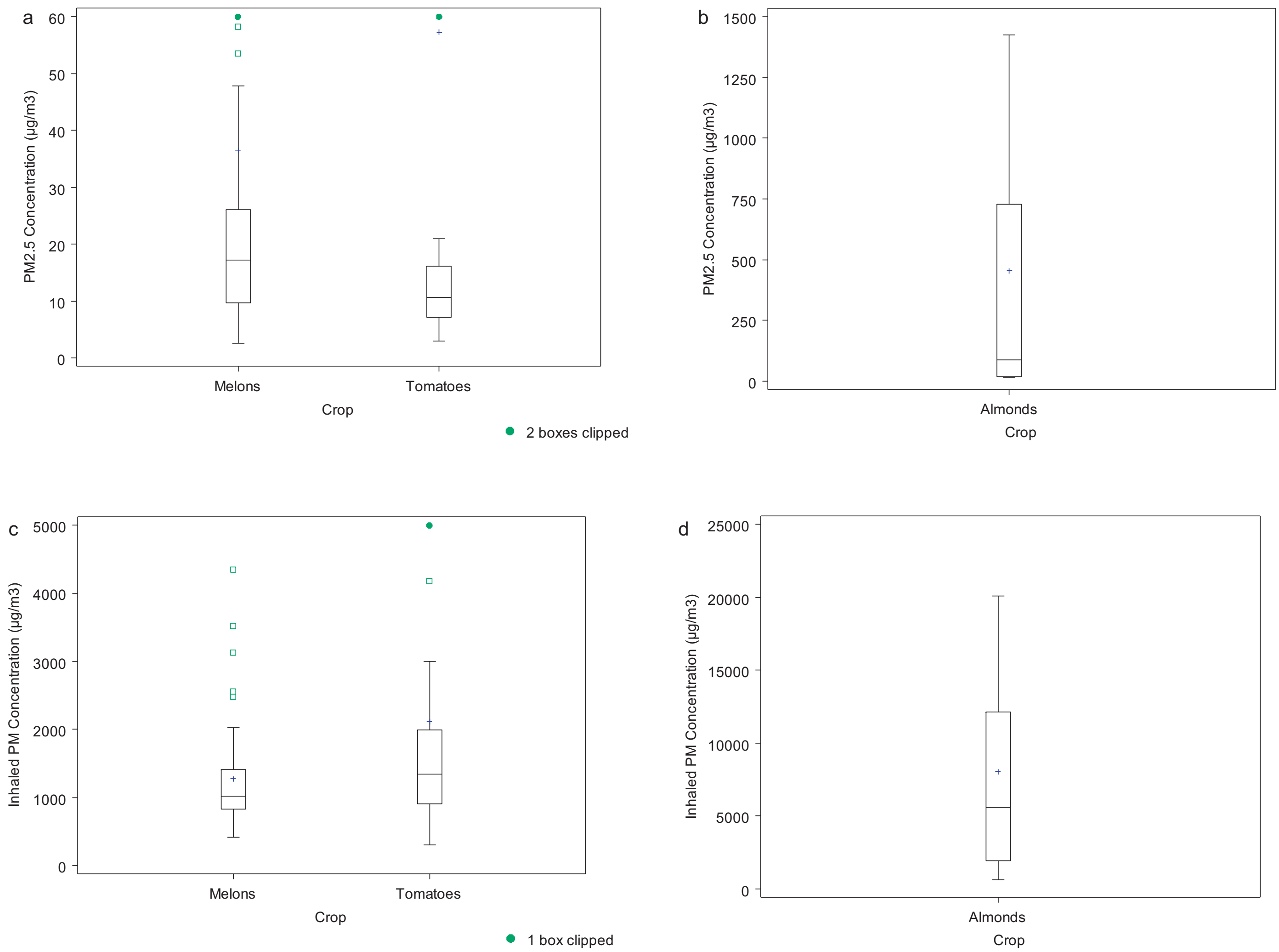

Fig. 1. Distribution of concentration distributions from personal exposure for workers in different crops as labeled (tomatoes $N = 33$, melons $N = 51$, and almonds $N = 5$). The boxplots represent the maximum, minimum, 75th percentile, 25th percentile, mean (+), median, and outliers (represented by small square) as defined by values that are 1.5× interquartile above the 75th and below the 25th percentile. Boxes clipped are those boxplots that have values excluded for scale purposes. (A) PM2.5 personal exposure concentration distribution for workers in melons and tomatoes; (B) PM2.5 Personal exposure concentrations distribution for workers in almonds; (C) inhalable PM personal exposure concentration distribution for workers in melons and tomatoes; (D) inhalable PM Personal exposure concentrations distribution for workers in almonds. *Note*: There is a difference in scale between almonds and melons and tomatoes.

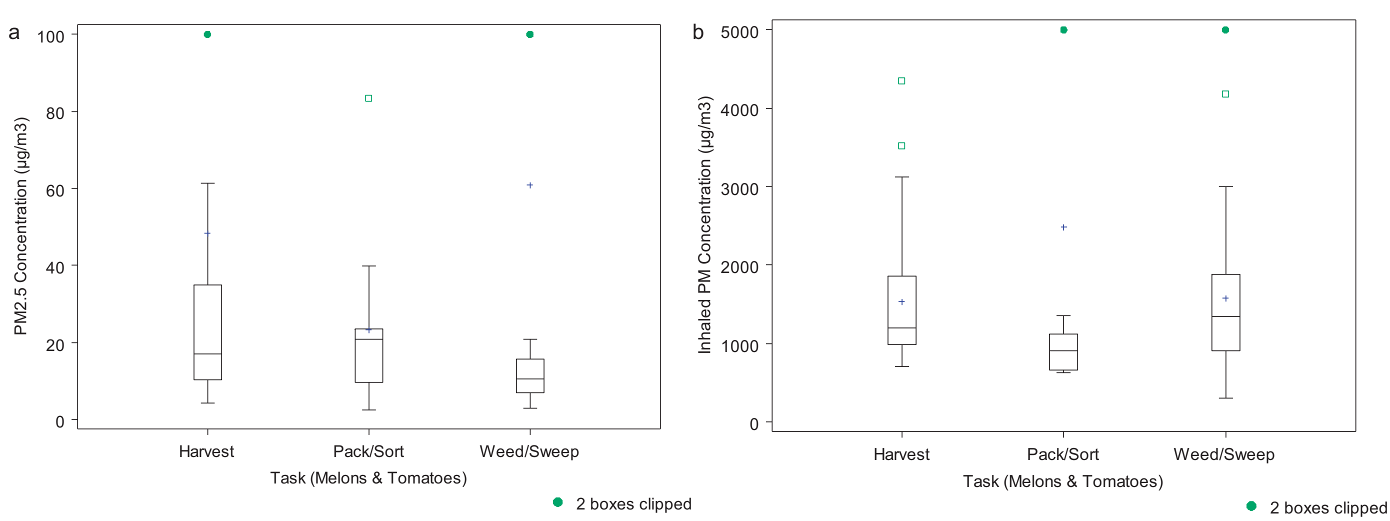

Fig. 2. (a) Personal occupational exposure $PM_{2.5}$ concentration distributions for workers performing a single task in melon and tomato crops. Harvest = harvesting of fruit ($N = 32$), pack/sort = packing and sorting of fruit ($N = 12$), weed/sweep = weeding and sweeping ($N = 29$) and (b) personal occupational exposure concentration distributions of inhalable PM by task for melons and tomatoes.

Table 1
Description of job tasks for workers in three crops (melons, tomatoes, and almonds).

	Definition/description		
Task	Melon	Tomato	Almond
Harvesting (hand and machine)	Melons are hand harvested, which involves picking and cutting them off the stem.	Tomatoes are both hand and machine harvested, depending on the type (processing vs. market).	Almonds are harvested by machines grabbing the trunk of a tree and shaking it. This causes the almonds to fall into the machine. For the almonds that remain on the branches, a crew comes later to knock the almonds down by using a rod/stick. Once the almonds fall to the ground, a machine comes by and sweeps them up.
Packing and sorting	Packing and sorting generally done in the field involves sorting melons by size and placing them in boxes for transport via trucks to a cooling facility.	For both hand and machine, packing and sorting are done in the field. Machine harvested tomatoes are transported via trucks to a processing plant. Handpicked tomatoes are transported via trucks to a cooling facility.	Packing and sorting is not done in the field. They are done at a processing plant.
Weeding and sweeping	Weeds are frequently removed from around the vines and throughout the growing season prior to harvest by hoeing until the melons are visible on the stems.	Same process as for melons	While the crew knocks the remaining almonds off the branches, other crew members sweep the almonds to the middle aisle to allow the machines to sweep them up*.

Sweeping is only done for almonds, and weeding is not necessary for this crop.

Regression models revealed no significant differences in exposure levels by task for workers in melons and tomatoes. Almond workers were not considered in the model because of limited observations and because the concentration distribution for almond workers was significantly higher than for melon or tomato workers.

Spearman correlation coefficients ($r = 0.35$, $P = 0.001$) demonstrated an association between regional $PM_{2.5}$ concentrations and personal $PM_{2.5}$ concentrations, indicating that exposures to $PM_{2.5}$ are moderately influenced by regional background levels, which tend to be high in the central valley of California. There was no correlation between personal $PM_{2.5}$ and inhalable PM concentrations.

Actual versus perceived exposure

Self reported exposure is used frequently in epidemiology studies to identify general exposure to dust in the workplace. To evaluate the effectiveness of "self reporting," correlation coefficients were calculated between the perceived exposures to dust versus the actual concentration measured by personal sampling. A significant correlation was found for those workers who had fewer than four years working in crops. However, as time working with a crop increased, the ability to accurately predict exposure decreased, as observed by lower correlation coefficients (Table 2).

Discussion

The purpose of this study was to determine farm worker exposure to particulate matter in both the respirable and inhalable size fractions. Three crops, tomatoes, melons, and almonds were included in this study. Two of the crops, melons and tomatoes, were the most predominant crops worked on by subjects in the larger MICASA study. Almonds were selected because of the likelihood of higher PM exposure in addition to having MICASA participants working with this crop. Almond harvesting includes the use of machinery to shake the trees, which is likely to resuspend significant quantities of PM. In contrast, tomatoes and melons, as investigated in this study, are harvested by hand, which, while more labor intensive, is less likely to resuspend PM. While hand harvesting is less likely to resuspend significant amounts of PM, it requires many more farm workers to be in the fields, thus a larger population is exposed to any PM that does become resuspended. An earlier study conducted in California that included hand harvesting and measured exposure levels have reported values of a similar magnitude to those in this study, although the sample size was small (Nieuwenhuijsen et al., 1999). That same study also reported that workers that were machine harvesting trees had over 10 times higher exposure levels than workers that were hand harvesting vegetables (Nieuwenhuijsen et al., 1999), as we found in this study. Concentrations of PM were also higher than those observed in other agriculture industries, such as concentrated animal feeding operations (Burch et al., 2010; Kullman et al., 1998). These data also demonstrate vast differences between tree based crops and row crops, likely due to more open exposed soil and greater soil pertubation in tree crops.

More research is needed on the composition of dust and mineral content of agricultural dusts in dry climate farming (Schenker et al., 2009). While recent research has shown that inorganic dust exposure is associated with a variety of adverse respiratory effects, the specific effects may depend on the dust size and composition as well as the exposure concentration. Larger size particles will tend to increase the risk of upper airway irritant effects, while smaller dust particles and dust with a greater concentration of crystalline silica or inorganic silicates may pose a higher risk of interstitial disease including pneumoconiosis (Schenker, 2010; Schenker et al., 2009). One should also consider that the inhalation rate may be increased when conducting labor intensive agriculture work, such as hand harvesting.

Previous epidemiology studies have used self reporting to evaluate exposure (Nieuwenhuijsen et al., 1997). In this study, self reporting was fairly accurate with actual exposure by workers

Table 2
Spearman correlation coefficients between perceived and actual inhalable exposure concentration by years worked in crop.

Years in crop	N	Perceived/Actual exposure
<2	28	**0.46**
<3	38	**0.39**
<4	45	**0.35**
<5	58	0.23*
<6	60	0.19

Bold numbers, $P < 0.05$.
* $P < 0.10$; non-bold numbers, $P = 0.15$

with fewer than 4 years working in the same crop, while no correlation was observed in workers who had worked in specified crop for longer than 4 years. This may be due to workers being less concerned with dust levels in the workplace the longer they work with a crop. This finding helps identify the need to include factors in the questionnaire data, such as time spent working in crop or in agriculture, when using only self reported values for determining risk by exposure for farm workers in epidemiology studies.

Associations between many types of agricultural work and respiratory symptoms have been found in previous studies (Schenker et al., 1998). While levels of PM exposure have been quantified for individuals doing machine preparation and harvesting, little was known about exposures for the numerous workers conducting hand harvesting. Levels of PM exposure in this study are significantly lower than for machine harvesting, however, mean levels still exceeded 1 mg/m^3, higher than many other occupational exposures. Almond workers had higher levels of exposure and targeted efforts should be made to reduce dust exposure among workers in this commodity.

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