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Occupational exposure to respirable and inhalable dust and its components in a Nicaraguan sugarcane plantation

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ABSTRACT

Objective To assess personal exposure to respirable and inhalable dust and its components endotoxin, black carbon and crystalline silica among sugarcane workers in Nicaragua.

Methods Individual exposures to respirable (measurements=98) and inhalable (measurements=36) dust were collected in January and March 2020, with the month of March generally being hotter and less humid. Respirable dust and its components black carbon and crystalline silica, as well as inhalable dust and its component endotoxin, were personally measured. Linear mixed models were used to identify the determinants of occupational dust exposure considering different job tasks and meteorological conditions.

Results Respirable dust and black carbon concentrations were higher in March among burned cane cutters compared with the other job groups (respirable dust geometric mean (GM)=1.9 mg m^{-3}; black carbon GM=13.7 µg m^{-3}), with considerably lower levels in January (respirable dust GM=0.2 mg m^{-3}; black carbon GM=3.4 µg m^{-3}). Almost all respirable crystalline silica measurements were below the limit of detection, except for four measurements, which ranged from 8 µg m^{-3} to 15 µg m^{-3}. Seed cutters (GM=3.1 mg m^{-3}) and weeders (GM=2.5 mg m^{-3}) had the highest exposure to inhalable dust, while endotoxin concentrations were higher among seed cutters (GM=100 EU m^{-3}) and burned cane cutters (GM=63 EU m^{-3}) than the other work groups.

Conclusions Overall, exposure levels to the assessed agents varied across work groups, with higher levels observed among burned cane and seed cutters.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous research has shown that, in addition to broad exposure to heat strain, working in sugarcane fields of Central America can involve exposure to other stressors, including silica in both amorphous and crystalline forms.

WHAT THIS STUDY ADDS

⇒ This is the first study to simultaneously assess exposure to respirable and inhalable dust, as well as dust components such as crystalline silica, black carbon and endotoxin, among different groups of sugarcane workers.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The study provides valuable insight into exposure of sugarcane workers to dust and its components.

⇒ The study informs future exposure and epidemiological studies on the health effects of these exposures on sugarcane workers, alongside other potential risk factors such as workload and heat stress.

INTRODUCTION

Production of sugarcane is increasingly mechanised, but manual work is still prevalent worldwide. Sugarcane workers are exposed to hot climate conditions, mineral and biological dust from the soil and (burned) sugarcane, heavy physical workload and risk of accidents.[1] Particulates generated by intense burning of cane during the harvesting season are a well-known respiratory hazard in the general population.[2 3] Few investigations have been performed on sugarcane workers, but a Brazilian panel study showed increased symptoms and decreased lung function over the harvest period among cane workers.[4]

More recently, it has been suggested that exposure to particulate matter, especially silica, is not only a respiratory hazard but also a potential risk factor for kidney disease. There is strong evidence from observational and intervention studies that heat stress is a major driver of the high prevalence of acute and chronic kidney disease not related to traditional risk factors observed among Mesoamerican sugarcane workers.[5–8] However, a silica hypothesis has also emerged based on observations of amorphous particles (nanoparticles) in kidney tissue from patients with chronic kidney disease not related to traditional risk factors (CKDnT)[9] and laboratory experimental studies.[10] However, occupational exposure assessments and epidemiological studies are still lacking. In non-agricultural settings, high occupational exposure to crystalline quartz[11] and inorganic dust[12] has also been associated with an increased risk of chronic kidney disease (CKD).

In sugarcane fields, amorphous and crystalline silica can be present in soil, depending on the actual soil type. Silica also occur in an amorphous

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form in sugarcane plants,[13] and small amounts can be partially transformed into crystalline structures during the preharvesting burning due to extreme temperatures from 400°C to around 1325°C.[14] In some settings, residual ash left in the field after preharvest and postharvest burning can contain some crystalline silica.[14 15] As a result, not only burned cane cutters but also workers involved in planting, weeding and harvesting may be exposed.

The overall aim of the present exploratory study was to provide a better characterisation of dust exposure among sugarcane workers to inform future epidemiological studies. Increased levels of particulate matter (2.5) in sugarcane fields during the harvest season have been documented[4]; however, assessments of dust fractions and the components during specific sugarcane work activities have, to our knowledge, not been performed.

Our investigation focuses on respirable and inhalable dust, known to cause various respiratory conditions ranging from acute toxic effects to long-term outcomes such as airway irritation, asthma exacerbation and inflammatory processes.[16–19] Furthermore, we assessed relevant dust components including crystalline silica, black carbon and endotoxin. Black carbon can stimulate cytokine and chemokine secretion due to macrophage clearance activity in the acinar airways,[20 21] while endotoxins pose a risk of inflammatory responses.[6 22] Full-shift personal measurements were performed in January and March 2020 to capture meteorological variations over a harvest period.

METHODS

Study area

The sugarcane plantation, Ingenio San Antonio, is located in Chichigalpa, Nicaragua, in one of the main CKDnT hotspots in Mesoamerica.[23] Efforts to prevent heat stress have been in place for at least 10 years but were intensified and systematically evaluated by the Adelante Initiative (https://adelanteinitiative.org) and the following PREP (Prevention Resilience Efficiency and Protection) research programme. The present study was part of a series of investigations on exposure to heat and other environmental contaminants. The study took place for 7 days in January 2020 and 14 days in March 2020. The work procedures were similar during these periods, but the weather conditions were different, with increasing temperature and lower relative humidity in March.

Study population

Sugarcane workers aged 19–51 were recruited during the harvest season in January (k=62; 6 women) and March (k=71; 17 women). The workers were recruited from seven work groups: burned cane cutters (k=35), seeders (k=20), seed cutters (k=19), reseeders (k=18), drip irrigation repair workers (k=18), gravity irrigators (k=13) and weeders (k=10). For reasons of feasibility, gravity irrigators were only studied in January and weeders only in March. All other groups were investigated in both months. A convenience sampling procedure was used. Participants within each work group were selected based on their availability on a given day of the measurement campaign, with the number of participants determined by the amount of equipment available for conducting measurements. Workers were observed throughout their work activities to document the duration of time allocated to specific work tasks, such as 'cutting sugarcane', 'packing seed cane', 'seeding seed cane', 'digging to plant seed cane' and 'periods of inactivity'. Figure 1 shows images of workers during different activities.

Exposure measurements

Full-shift personal measurements were collected from the breathing zone of the workers.

Respirable dust levels, which refer to particles capable of penetrating the alveolar region of the lungs and have a 50% cut-off at d_{ae} of 4 µm, were sampled using Dorr-Oliver Cyclone sampling heads operated at a flow rate of 1.7 L/min loaded with polyvinyl chloride (PVC) 37 mm filters (pore size 5.0 µm; Millipore).

A Smoke Stain EEL Model 43D reflectometer was used to measure the light absorption coefficient of the exposed filters to estimate the equivalent black carbon concentrations using the Virkkula *et al* equation[24]:

$$eBC\ \left(\mu g\ m^{-3}\right) = \frac{A \times 10^6}{2V \times \sigma_{ATN}} \ln\left(\frac{R_0}{R}\right)\left(1 + k \ln\left(\frac{R_0}{R}\right)\right)$$

where the light absorption coefficient $\ln\left(\frac{R_0}{R}\right)$ was measured for each filter, A is the area of the exposed filter and V is the volume of air sampled. The mass extinction coefficient σ_{ATN} and a correction factor k for Teflon filters were obtained from Davy *et al*.[25] We additionally adjusted for differences in light absorption properties between PVC and Teflon filters in our laboratory using a factor of 1.2.

Thirty respirable fraction samples from January were analysed for respirable crystalline silica (RCS), with approximately five samples collected for each of the following working groups: burned cane cutters, seed cutters, drip irrigation repairers, reseeders, gravity irrigators and seeders. An infrared spectrophotometry method (Fourier Transform Infrared Spectroscopy (FT-IT)) was used to determine the concentration of crystalline silica on filters.[26] The limit of detection was 5 µg as reported in the *NIOSH Manual of Analytical Methods (NMAM) - Fourth Edition*.[27]

Sampling for inhalable dust, which includes airborne particles up to 100 µm, was conducted only in March using PAS-6 inhalable dust samplers[19] containing 25 mm PVC filters (pore size 5.0 µm; Millipore) operated at a flow rate of 2 L/min. After collection, filters were stored at −20°C until shipment to the Netherlands at 4°C.

For endotoxin extraction, these 25 mm PVC filters were immersed in 5 mL pyrogen-free water plus Tween 20 (0.05% v/v). After shaking for 60 min at room temperature, the tubes were centrifuged for 15 min at 1000× *g*. Supernatants were harvested and stored in 0.1 mL aliquots at 20°C until analysis. The endotoxin concentration was determined in supernatant using a quantitative kinetic limulus amoebocyte lysate method.[17 19]

Pregravimetric and postgravimetric analyses were performed to estimate dust concentrations of both respirable and inhalable dust filters using the Mettler MT5 Microbalance (Mettler Toledo, Greifensee, Switzerland), with 1 µg reading in a preconditioned room at 20°C and controlled 37%–40% humidity. In addition, two field blanks based on each shift per day were collected to control for cross-contamination.

Meteorological information on wet-bulb globe temperature (WBGT), relative humidity and wind speed was collected using either the QUESTemp34 (3M) or the Kestrel Monitoring System during each work shift commonly from 06:00 until shift end at around 14:00, except for burned cane cutters, who stopped work between 11:00 and 12:00.

Statistics

Exposures of job groups appeared to follow a lognormal distribution. Therefore, geometric mean (GM) and geometric standard deviation (GSD) were used to describe exposure distribution

Figure 1 Workers during their activities in the sugarcane plantation: (A) burned cane cutter, (B) seed cutter, (C) weeder, (D) drip irrigator repair worker, (E) seeder, (F) reseeder and (G) gravity irrigator. The photographs were taken by E.Kashi/VII, A.d'Errico, J.Woodruff and K.Jakobsson.

functions to mitigate right skewness and improve goodness of fit of the statistical models.

Linear mixed-effects models with random intercept were used to estimate exposure differences by job tasks, accounting for exposure variability between and within work groups using R *lmer4* package.[28] Job tasks were incorporated as fixed effects, while the random-effects component with random intercept accounted for job groups. We also explored the influence of specific job-related tasks as covariates to estimate their respective contributions to workers' exposure levels. Tasks were assigned to a worker if they were performed for at least one-third of the working shift. Results were reported as GM ratio, which is the ratio of exposure levels when the job task was present compared with when the job task was not present. Furthermore, our modelling approach incorporated environmental factors, specifically WBGT, relative humidity and wind speed, to elucidate their influence on exposure levels. Results are presented as the percentage change of workers' exposures relative to meteorological conditions.

To compare measured concentrations with occupational exposure limit values (OELVs), we used the standardised tests outlined in the European standard EN 689:2018 for similarly exposed groups. The statistical methods are described in Annex F of EN 689:2018.[29] Briefly, when there were six or more measurements within a job group, we used the upper tolerance limit ($UTL_{95,70}$) with a 95% confidence limit and a 70% confidence level as the threshold parameter for OELV exceedance. When $UTL_{95,70}$ is greater than the OELV, the job was considered 'above the threshold'. For groups with four or five measurements, a preliminary test was applied by comparing work group measurements with, respectively, 0.15 or 0.2 times the OELV. If any exposure within a group exceeded the OELV, the group was classified as 'above the threshold'. If any exposure within a job was above 0.15 or 0.2 times the OELV but below the OELV, the decision was considered 'uncertain' because exposure neither exceeded nor was below the threshold. The group was considered 'below the threshold' only if all measurements were below, respectively, 0.15 or 0.2 times the OELV. The OELVs used for respirable and inhalable dust were 1.25 mg m^{-3} and 4 mg m^{-3}, as suggested by the German BAuA (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin),[30] and 90 EU m^{-3} for endotoxins, as recommended by the Dutch Expert Committee on Occupational Standards.[31] The recent update of these OELs aims to prevent non-specific effects of dust where general limit values might not apply, particularly in cases where other soluble, ultrafine or coarse particulate fractions are present. For RCS, Occupational Safety Health Administration (OSHA's) permissible exposure level of 25 µg m^{-3} was used.[32] For black carbon, no OELV was available.

RESULTS

Climate conditions

In January, the average WBGT measurement over the 7 study days was 27.7°C (SD=0.7), ranging from 16°C–18°C during the early hours of shifts (06:00–06:30) to 32°C–33°C in the later hours of shifts (13:00–14:00). Over the 14 days in March, the average WBGT was slightly higher at 28.8°C (SD=1.0), with measurements ranging during the day from 19°C–20°C to 34°C–35°C. In January, daily temporal variations in relative humidity had a mean of 54.5% (SD=2.7). Higher variability between days than within days was observed, with usually higher relative humidity at 06:00–06:30 of between 50% and 90% than at 09:00–14:00 with relative humidity of between 35% and 50%. In contrast, the study days in March recorded a lower mean humidity level of 44.2% (SD=12.6) but with similar trend for temporal variation within days. Wind speed data in both January and March showed an average of approximately 2 m/s (SD=1.0). In both months, wind speed varied more between than within working days.

Exposure measurements

Findings on exposure to respirable and inhalable dust, crystalline silica, black carbon and endotoxins per job group, along with the number of workers and the average worktime, are shown in table 1. Most measurements were collected to assess exposure to respirable dust and black carbon (n=98), followed by inhalable dust and endotoxin measurements (n=36) and RCS (n=29). The highest number of measurements for a job grouping (n=76) was for burned cane cutters.

Burned cane cutters had the shortest average working time, while reseeders had the highest average working time. Figure 2 shows the respirable dust (mg m^{-3}) and black carbon (µg m^{-3}) concentrations for each job during both January and March. In summary, there was a considerable difference in respirable dust concentrations between January (GM=0.3 mg m^{-3}, GSD=2.9) and March (GM=0.8 mg m^{-3}, GSD=2.8). Respirable dust concentrations were generally higher for all groups in March, except for the seeders, who showed higher exposures in January (GM=0.7 mg m^{-3} in January vs GM=0.3 mg m^{-3} in March). Burned cane cutters experienced the highest exposure to respirable dust (GM=0.8 mg m^{-3}, GSD 3.9, range 0.4–4.6) and showed the largest (sevenfold) difference between the 2 months (GM=0.2 mg m^{-3} in January vs GM=1.9 mg m^{-3} in March). Similar patterns across the job groups were seen for exposure to black carbon.

The differences in average exposure levels between job groups were found to be somewhat larger for respirable dust by a factor of ~6, compared with black carbon, which showed a relatively smaller difference between the job groups by a factor of ~4.

Almost all 29 RCS measurements were below the analytical limit of detection of 5 µg per filter (5.2 µg m^{-3} for an 8-hour measurement). Four measurements exceeded the limit of detection, resulting in an RCS concentration of 15.0 µg m^{-3} for a reseeder, 13.6 µg m^{-3} for a gravity irrigator and 8.1 and 13.0 µg m^{-3} for two burned cane cutters.

Inhalable dust (mg m^{-3}) and endotoxin (EU m^{-3}) concentrations appeared to be highly correlated (r=0.75) (see figure 3). The highest exposures to inhalable dust were seen in seed cutters (GM=3.1 mg m^{-3}, GSD=1.7) and reseeders (GM=2.5 mg m^{-3}, GSD=1.3). Endotoxin levels were also observed to be highest in seed cutters (GM=100 EU m^{-3}, GSD=2) and burned cane cutters (GM=63 EU m^{-3}, GSD=2), showing a nearly tenfold and sixfold increase compared with the other groups, respectively. Lower exposure levels of inhalable dust (GM between 0.5 mg m^{-3} and 0.9 mg m^{-3}) and endotoxins (GM between 5 EU m^{-3} and 12 EU m^{-3}) were found for seeders, weeders and drip irrigation repair workers.

Table 1 shows the comparisons with OELVs according to EN 689:2018 for each job. Burned cane cutters' and seed cutters' exposures clearly were above the OELVs for all tested agents, while for all other jobs exceedance of the OELV for inhalable dust was uncertain. The exposure levels for respirable dust were above the OELV for seeders and reseeders, whereas drip irrigation workers and weeders had exposures clearly below the OELV. For exposure to endotoxins, drip irrigation repair workers and seeders showed exposures below the OELV, while for weeders and reseeders this was uncertain.

Table 1 Results of the assessment of exposure concentrations to inhalable dust, respirable dust, endotoxin and black carbon for each job group, and compliance with OELV

Job (k) (sampling time AM; SD (min))*	Inhalable dust† (mg m^{-3}), AM GM (GSD) (n) (EN 689:2018 test)	Respirable dust‡ (mg m^{-3}) GM (GSD) (n) (EN 689:2018 test)	Endotoxin‡ (EU m^{-3}) GM (GSD) (n) (EN 689:2018 test)	Black carbon‡ (µg m^{-3}) GM (GSD) (n)
All (k=133) (284; 65)	1.7 (2.7) (36)	0.4 (3.2) (98)	30 (4) (36)	3.8 (2.3) (98)
Burned cane cutters (k=35) (249; 43)	2.2 (3.2) (13) (A)	0.8 (3.9) (23) (A)	63 (2) (12) (A)	8.0 (2.8) (23)
Seed cutters (k=19) (310; 34)	3.9 (1.8) (5) (A)	0.4 (2.3) (14) (A)	100 (2) (5) (A)	4.0 (1.5) (14)
Seeders (k=20) (289; 56)	0.9 (1.5) (5) (U)	0.6 (2.6) (15) (A)	9 (1) (5) (B)	3.5 (1.9) (15)
Reseeders (k=18) (426; 2)	2.6 (1.3) (4) (U)	0.3 (2.9) (14) (A)	17 (2) (4) (U)	3.1 (1.5) (14)
Drip irrigation repair workers (k=18) (376; 8)	0.5 (2.4) (4) (U)	0.1 (2.3) (14) (B)	5 (1) (4) (B)	2.5 (1.4) (14)
Weeders (k=10) (343; 60)	1.1 (1.4) (5) (U)	0.3 (1.4) (5) (B)	12 (2) (5) (U)	3.1 (1.3) (5)
Gravity irrigators (k=13) (293; 58)		0.2 (2.8) (13) (A)		2.1 (2.4) (13)
OELV				
	MAK: 4 mg m^{-3}	BAuA: 1.25 mg m^{-3}	DECOS: 90 EU m^{-3}	

According to the EN 689:2018 strategy for testing compliance with occupational exposure limit values, A is above the threshold; U is uncertain, neither exceeding nor below the threshold; and B is below the threshold.
*Daily worktime recorded during January and March.
†Sampled in March 2020.
‡Sampled in January and March 2020.
AM, arithmetic mean; BAuA, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin; DECOS, Dutch Expert Committee on Occupational Standards; GM, geometric mean; GSD, geometric standard deviation; k, number of workers; MAK, maximale Arbeitsplatz-Konzentration (maximum workplace concentration); min, minutes; n, number of measurements.

Table 2 shows the results of the linear mixed models with job tasks and meteorological conditions. The task 'cutting sugarcane' emerged as a primary determinant consistently contributing to an increase in all exposure agents studied. The task of cutting sugarcane (green or burned) showed an eightfold increase in GM endotoxin levels and more than a twofold increase for the other four agents compared with exposure levels when the task was not performed. The tasks 'seeding cane' and 'digging to plant seed cane' as well as 'periods of inactivity' resulted in lower exposure concentrations, although the precision of all these estimates was limited.

The impact of meteorological conditions is also seen in table 2. Although the CIs were large, a 1°C rise in WBGT resulted in an increase in exposure levels for all agents, while increases in relative humidity resulted in lower exposure concentrations for all agents.

DISCUSSION

Higher exposure levels were reported during harvesting activities in March, particularly in concentrations of respirable dust and black carbon, predominantly among burned cane cutters, who are engaged in highly active manual work. Higher WBGT levels were recorded in March compared with January, with the most notable difference in meteorological conditions being lower relative humidity in March. Task analyses showed patterns consistent with the job group analyses. Also, the elevated exposures observed can be primarily attributed to preharvest burning practices and dry soil conditions, generating more dust. These conditions differ from those faced by other work groups who operate on wetter soils; nevertheless, using statistical tests according to EN 689:2018, some of these work groups, such as the seeders, reseeders and gravity irrigators, were also found to have concentrations above the OELV, with an OELV of 1.25 mg m^{-3} for respirable dust.

In a recent study conducted in Guatemala by Schaeffer *et al*,[33] 11 personal air samples were collected from researchers serving as proxies carrying out the work of cane cutters. They reported an average of 0.4 mg m^{-3} for respirable dust, which was almost half of our overall average (AM=0.7 mg m^{-3}), and their average (AM=0.5 mg m^{-3}) for inhalable dust was much lower (five times) than reported here (AM=2.7 mg m^{-3}). However, the authors acknowledge the potential underestimation of exposure due to the use of investigators as proxies for burned cane cutters. Like the findings reported here, they showed that all their RCS measurements collected were below the limit of detection.

Black carbon appeared to be a relatively minor component of respirable dust and most likely originated from the burning prior to cutting cane the next day. Ash particles larger than 1 µm usually deposit on the soil nearby[34] and could result in exposure during consequent harvesting/cane cutting. The average concentrations among all groups of sugarcane workers ranged from around 2 µg m^{-3} to 8 µg m^{-3}, being somewhat higher among burned cane

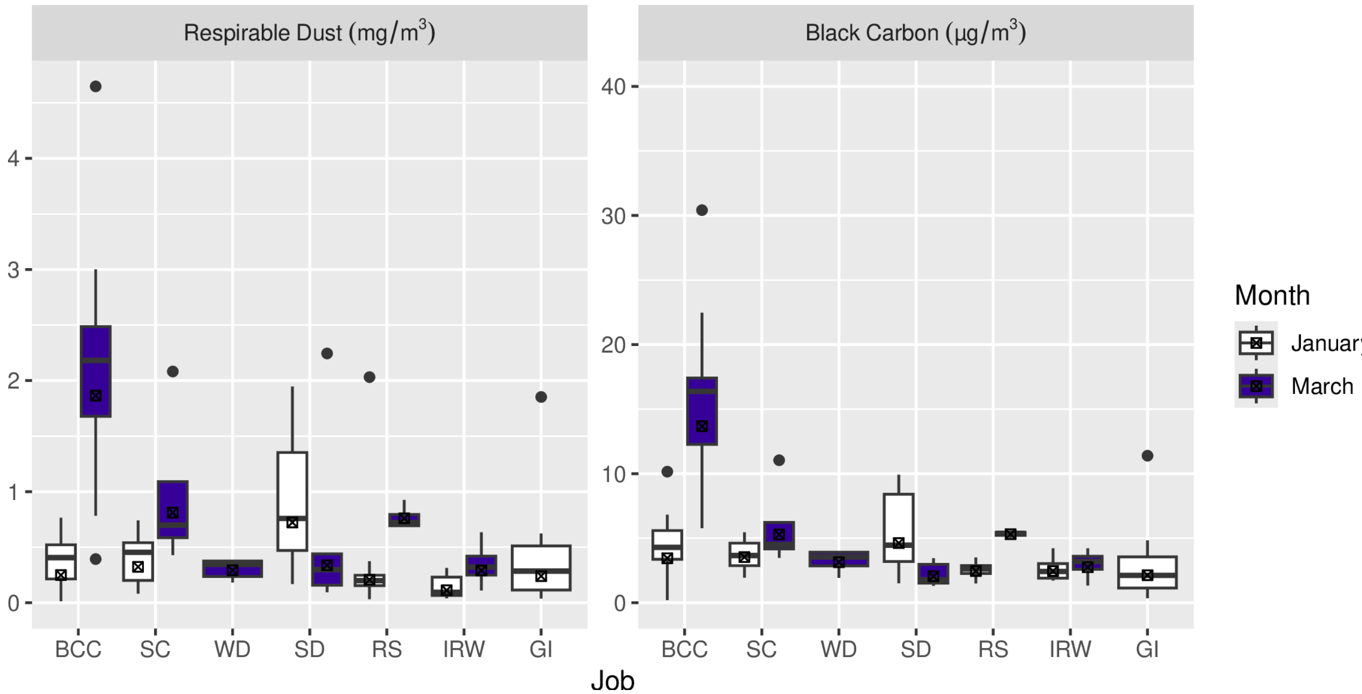

Figure 2 Respirable dust (mg m^{-3}) and black carbon (µg m^{-3}) concentrations by job type in January and March. '⊠' stands for geometric mean. Number of measurements by job group in January: BCC, k=9; SC, k=10; WD, k=0; SD, k=10; RS, k=10; IRW, k=10; GI, k=13. Number of measurements by job group in March: BCC, k=14; SC, k=4; WD, k=5; SD, k=5; RS, k=4; IRW, k=4; GI, k=13. BCC, burned cane cutter; GI, gravity irrigator; IRW, irrigation repair worker; RS, reseeder; SC, seed cutter; SD, seeder; WD, weeder.

cutters in March probably due to meteorological conditions (higher temperatures and lower humidity). The heterogeneous nature and health impacts of black carbon should be considered when comparing findings in different occupations. Most studies focus on sources such as combustion engines (eg, diesel) or solid fuels used for domestic purposes. For example, studies in China have shown that personal average exposures ranged from 3 µg m^{-3} to 18 µg m^{-3} in rural households, primarily from domestic use of solid fuels.[35]

Overall, the levels of exposure to endotoxins, while highest among burned cane and seed cutters in close contact with the cane foliage, were relatively low across all groups of sugarcane

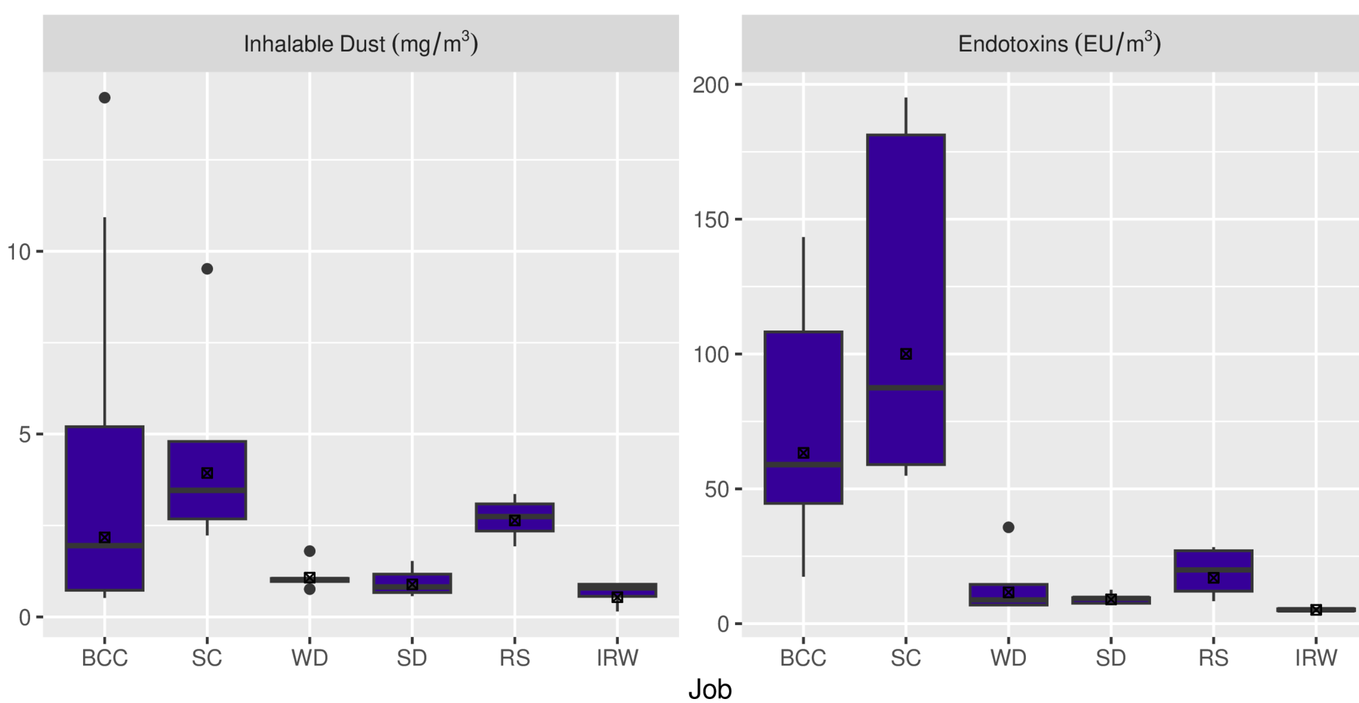

Figure 3 Inhalable dust (mg m^{-3}) and endotoxin (EU m^{-3}) concentrations by job type in March. '⊠' stands for geometric mean. Number of measurements by job group in March: BCC, k=13; SC, k=5; WD, k=5; SD, k=5; RS, k=4; IRW, k=4. BCC, burned cane cutter; IRW, irrigation repair worker; RS, reseeder; SC, seed cutter; SD, seeder; WD, weeder.

Table 2 Linear mixed models with random intercepts used to assess the impact of job tasks and meteorological conditions on exposure levels to respirable dust, black carbon, inhalable dust and endotoxin

Job task	Respirable dust GMR (CI)	Black carbon GMR (CI)	Inhalable dust GMR (CI)	Endotoxin GMR (CI)
Cutting sugarcane	2.17 (0.97 to 4.82)	2.05 (1.26 to 3.29)	2.61 (1.10 to 6.33)	7.93 (3.98 to 15.98)
Packing seed cane	0.82 (0.21 to 3.19)	0.86 (0.31 to 2.34)	1.00 (0.35 to 2.87)	0.48 (0.18 to 1.33)
Seeding cane	0.57 (0.24 to 1.32)	0.59 (0.34 to 1.04)	0.52 (0.11 to 2.53)	0.38 (0.03 to 4.92)
Digging to plant seed cane	0.54 (0.24 to 1.25)	0.55 (0.33 to 0.94)	0.70 (0.25 to 2.02)	0.71 (0.22 to 2.03)
Periods of inactivity	0.80 (0.17 to 3.62)	0.88 (0.29 to 2.67)	0.66 (0.12 to 3.41)	0.52 (0.04 to 7.27)
Meteorological conditions	**Respirable dust (mg m−3) % (CI)**	**Black carbon (µg m−3) % (CI)**	**Inhalable dust (mg m−3) % (CI)**	**Endotoxin (EU m−3) % (CI)**
WBGT (°C)	1.40 (0.98 to 2.00)	1.27 (0.95 to 1.60)	1.22 (0.89 to 1.65)	1.10 (0.84 to 1.42)
Wind speed (m/s)	1.04 (0.61 to 1.69)	0.91 (0.52 to 1.47)	0.88 (0.39 to 1.98)	0.77 (0.21 to 2.72)
Relative humidity (%)	0.95 (0.93 to 0.97)	0.95 (0.93 to 0.97)	0.99 (0.92 to 1.08)	1.00 (0.88 to 1.13)

GMR and % change >1 indicates higher exposure levels; GMR and % change <1 indicates lower exposure levels; GMR and % change of 1 indicates equal exposure levels.
GMR, geometric mean ratio; WBGT, wet-bulb globe temperature.

workers when compared with other agricultural settings. For instance, in primary grain, seed and legume production sectors such as potato and flax cultivation, arable farming and grain harvesting, endotoxin concentrations were considerably higher, with GM concentrations ranging from 2100 EU m^{-3} to 4470 EU m^{-3}.[36]

One of the strengths of the study is the assessment in two different months with varying meteorological conditions, which provided the opportunity to evaluate exposures during the dustiest period in March. Additionally, the study assessed several hazardous agents and evaluated both inhalable and respirable dust particulates that have independent potential to impact the respiratory tract. Measured concentrations were compared with OELV and the main determinants of exposure were unravelled.

Weaknesses include the limited number of subjects and samples collected, which may have contributed to lower precision in the exposure levels measured. Furthermore, the findings may not be easily generalised to other sugarcane plantations or similar settings due to differences in environmental factors (eg, climate, dustiness, volcanic soil and silica content, vegetation) and working conditions (eg, work practices and burning schemes, specific to each mill) faced by sugarcane workers.

CONCLUSION

This study showed considerable levels of inhalable and respirable dust exposure among sugarcane workers when compared with OELVs. Burned cane cutters were the most exposed group, notably experiencing the most hostile working conditions among these workers.

Considerable variability in concentrations of dust and its components was found between job groups and was influenced by climatic conditions. Thus, using the job title of a sugarcane worker alone appears to be an insufficient proxy for particulate exposures, and future work among sugarcane workers should consider more than job title alone when assessing particulate exposure. Notably, the levels of RCS were largely undetectable. Given these exposure levels, significant respiratory or kidney disease risks from RCS seem unlikely among these workers.

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Contributors Ad'E, SP, DHW, KJ and HK conceptualised and designed the study. Ad'E and SP collected the data. Ad'E, SP and IMW performed the laboratory analysis. Ad'E and HK performed the statistical analysis, with support from DHW and KJ. Ad'E, DHW, KJ, HK and IMW drafted the manuscript. All authors contributed to the editing of the manuscript, and all authors read and approved the final manuscript. Ad'E is responsible for the overall content as guarantor.

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Competing interests None declared.

Patient consent for publication Not required.

Ethics approval This study involves human participants and the workplace studies were conducted in accordance with the Declaration of Helsinki and approved by the institutional review board of the National Autonomous University of Nicaragua at León (UNAN-León) (Comité de Ética para Investigaciones Biomédicas-CIEB; protocol code FWA 00004523/IRB 00003342, approval date 29 September 2017; approved amendments 14 October 2019 and 13 May 2020). Participants gave informed consent to participate in the study before taking part.

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