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Particulate matter exposure of combine harvester operator during wheat harvesting in northern India

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ABSTRACT

A study was carried out to assess the quantum of particulate matter in the breathing zone and workspace of combine harvester operator during 2018-19 in wheat fields of ICAR-Indian Agricultural Research Institute, New Delhi. Mass concentration and particle size distribution of dust were assessed in the breathing zone for different size fractions related to health during wheat harvesting using a personal dust monitor. Sticky papers were used to determine the characteristics of particulate matter and wheat straw (>100 μm) in the workspace of the combine harvester. The average mass concentration of inhalable, thoracic and respirable particles were 9500, 4150 and 940 μg/m^3 and PM_{10}, $PM_{2.5}$ and PM_1 particles were 3722, 453 and 120 μg/m^3 in the breathing zone. Particulate matter concentrations were 37 and 8 times (daily basis) and 62 and 11 times (annual basis) higher than the permissible value of PM_{10} and $PM_{2.5}$. The equivalent diameter of wheat straw ranged up to 1400 μm with a density of 9-12 particles per mm^2 surface area. It amounts to 1.2 million particles in the workspace with the potential of sticking on exposed body of the operator considering a 10% body surface area.

Keywords: Combine harvester operator, Dust exposure, Particulate matter, Working environment, Wheat straw

The present population of combine harvester in India is 40000, with an addition of 5000 every year (Mehta *et al.* 2019). Combine harvesting of wheat produces a large amount of particulate matters (PM) on farm. The increased number of combine harvester employs a large number of operators.In low-income countries, operators are exposed to dust and other harsh environmental conditions as combines are not equipped with cabins, unlike developed nations. Operators are exposed to particulate matter and wheat straw during harvesting and threshing (Pandirwar *et al.* 2014). Due to the small window of the wheat harvesting period, the operator has to work for a long duration, even at night, consequently increasing the dust inhalation and ill effects of straw particles on the exposed body of the operators. In developed countries, cabins are installed on a combine harvester, which prevents dust exposure, results in a reduction of dust from 2 to 20 μg/m^3 to 0.1 to 1 μg/m^3 by air filtration (Kirkhorn and Garry 2000) and restriction of dust movement (Zander 1972). Exposure to dust and straw in high temperatures and dry weather with low relative humidity cause health problems (EPA 2019) along with operational difficulties.

Particulate matter less than 10 μm generated during agricultural operations constituting of $PM_{2.5}$ and $PM_{1.0}$ (Chen *et al.* 2016). PM_{10} produced during agricultural operations are most likely to cause ill health; however, particulate matter less than 2.5 μm ($PM_{2.5}$) penetrates the gas exchange regions of the lungs (Arslan *et al.* 2010) and adversely affects the bloodstream. Agricultural dust also carries harmful bacteria, fungal spores, mould spores, pesticide residues, endotoxins and mycotoxins (HSE 2007). Inhalation of grain dust is responsible for releasing histamine and leukotrienes from lung tissues, which may cause of acute broncho constriction among farmers (Behera *et al.* 2005). Other detrimental effects of dust exposure are inflammation of the eyes, lungs, and skin.Very few studies have been conducted on dust and wheat straw exposure of combine harvester operators in developing countries. The present study is conducted to assess the dust in the breathing zone and workspace of the combine harvester operator during wheat harvesting.

MATERIALS AND METHODS

Exposure assessments: Experiments were conducted for two consecutive years (2018 and 2019) at ICAR-IARI, New Delhi experimental farms on combine harvester without cabin for assessing the mass concentration (μg/m^3) of inhalable particulate matter including thoracic, respirable,

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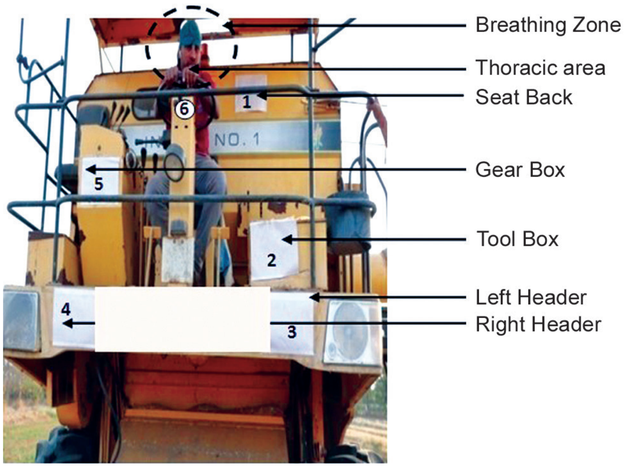

Fig 1 Assessment of particulate matter in breathing zone and workspace of combine harvester operator.

PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ using personal dust monitor in the breathing zone (Fig 1). A personal dust monitor had a limitation of measuring inhalable particles; therefore, an alternate sticky paper procedure was used to assess the particle size larger than the inhalable particle. Equivalent diameter (µm), number of particle (wheat straw>10 µm) per unit surface area (number/mm^2) were recorded using sticky paper at six locations in the operator workspace (Fig 1). Environmental factors like temperature, wind speed, relative humidity were measured on the day of the experiment (Table 1). Also, the harvesting parameters like moisture content during the harvesting, harvesting speed of combine harvester were also measured (Table 1). A total of six replicated data samples were collected from the field and analyzed.

Assessment of dust in the breathing zone of the operator

Experiments were performed to measure particulate matter in wheat harvesting by combine harvesters. Cabin less workspace of combine harvester is surrounded by a cloud of dust and straw particles during harvesting operation (Fig 1). The sample collection for particulate matter was performed in the breathing zone of operator. Different fractions for health-related measurement, namely inhalable, thoracic, respirable and size fraction of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were measured using a personal dust monitor. The dust measurement head was attached to the collar of the operator's shirt. The sample air was channelized into the measuring cell via the custom-designed air inlets at a sampling volume of 1.2 liters/minute. A modulated laser beam was used to detect the size range of particles. The intensity of scattered light signals classified particle size.

Table 1 Operational and environmental parameters measured during harvesting

Parameter	Values
Operational parameters	
Crop maturity- days after sowing	140 days
Crop moisture content during harvesting	8-10%
Harvester forward speed	2-2.5 km/hr
Height of cut from the ground	10 to 25 cm
Grain straw ratio	1:1.2
Speed of combine blower	1800 rpm
Environmental parameter	
Relative humidity (%)	48
Temp. (Max.) (℃)	39
Temp. (Main.) (℃)	18.8

Assessment of wheat straw particles in the workspace of combine harvester operators: During combine harvesting, the crop is threshed, converting crop biomass into small straw particles, which are blown out. Sticky papers of size 29.7 cm × 21 cm were pasted for collecting wheat straw samples at the thoracic region of the operator, toolbox, gearbox, left and right header and seatback of combine harvester operator workspace. The experiments were conducted for 15 minutes. The collected samples on sticky paper were further processed to find particle size distributions and the number of particles per unit surface area. Image vision technique was used to distinguish the particles with the microscopic camera that captured images of samples collected on sticky paper. Captured images were processed using "bio-vision" particle size analyzer software to determine the total number of particles, equivalent diameter of each particle and density of particles. Particles were separated from each other using the edge detection method and the dimension was measured by applying a calibrated value of pixel length in the sample image. The particles greater than 10 µm equivalent diameter were considered for the study because of the limitation of the image processing technology. However, particles less than 10 µm were assessed and analyzed in the operator breathing zone. The process involved digital image acquisition, image processing, analysis and evaluation.

RESULTS AND DISCUSSION

Dust concentration in the breathing zone: A wide range of dust particles in the breathing zone of the operator was observed (Table 2). It consisted of different fraction mass concentrations. The average dust concentrations observed were 9500, 4150, 940 µg/m^3 for inhalable, thoracic and respirable particles, respectively, whereas 3722, 453 and 120 µg/m^3 for PM_{10}, $PM_{2.5}$ and $PM_{1.0,}$ respectively. The particulate matter concentrations were much higher than the permissible value. Observed dust concentrations were 37 and 8 times higher than the permissible value on a 24-hour basis and 62 and 11 times on an annual basis (NAAQS 2009) for PM_{10} and $PM_{2.5,}$ respectively. The concentration of PM_{10}, and thoracic dust particles were in high proportion compared to $PM_{2.5}$, $PM_{1.0}$ and respirable particles. Variations in mass concentration throughout the observation period were because of continuous change in wind speed and direction, which governs the concentration of dust particles around the operator in an unenclosed space.

Absence of a cabin, the operator is exposed to the environment of highly concentrated inhalable dust consisting of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$. In India, NAAQS (2009) has limits for PM_{10} as 60 µg/m^3 (annual) and 100 µg/m^3 (daily) and for $PM_{2.5}$, 40 µg/m^3 (annual) and 60 µg/m^3 (daily). In the present study, average concentrations observed for PM_{10} and $PM_{2.5}$ were 3722 and 453 µg/m^3, respectively. When compared with permissible limits of Indian NAAQS and US NAAQS (1990), they were 62 and 74, 37 and 25 times for $PM_{10;}$ 11 and 30, 8 and 13 times for $PM_{2.5}$ on an annual and daily basis, respectively. This is an alarming issue in the Indian context for effect on the operator's health. Operators may not be aware of the ill effects of poor environmental conditions without any provision for environmental monitoring; it may lead to a detrimental effect on farmer's health. Organic dust exposure is responsible for respiratory diseases and anyone working in agriculture is exposed to a certain level of organic dust (Thaon *et al.* 2011). Exposure to grain dust may result in acute and chronic respiratory problems and reduced lung function (Huy *et al.* 1991, Becklake 2007). The dust varies for tractor/harvester operators throughout the year and both drivers and farmers were subjected to high dust levels during summer (Arslan and Ali 2012). Arslan *et al.* (2010) reported PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ concentrations as 29300, 10560 and 3130 µg/m^3 in wheat harvesting, which were higher than the observed values of particulate matter in the present study. Both the work duration and dust concentration levels are vital for the operator's health. Air dynamics also plays an important role in particulate matter distribution and concentration. Particulate matter generated during agricultural operations disperses and spread by air movement (Förstner 1995). Contents of particulates matter depend on where, when and how the dust is generated (The Swedish National Board of Occupational Safety and Health 1994). The severity is reported by Jager (2005) as potential exposures in agricultural work environments are infinite. Weather conditions during harvesting season were harsh. Temperature varied from 40 to 46 ˚C with very dry season and average wind speed of 12.3 km/h; these accelerated the dust movement resulting in severe operator exposure.

Wheat straw concentration in operator workspace: A wide range of straw particles were produced during harvesting because of reciprocating motion of the cutter bar resulting in shearing of crop, threshing unit producing crop straw and blower unit blows away straw particles in the environment for cleaning the grain. Dust clouds at different locations were observed, moving in the combine harvester's workspace because of continuous wind movement. It was observed that the straw particle concentration and their size varied throughout the experiment in the workspace (Fig 2). The equivalent diameter of particles greater than 10 µm was considered. Particle size of 10.6 µm to 1325 µm deposited on sticky papers located in the thoracic region. A similar pattern of particle size was observed at other locations also like toolbox (10.9 to 1369.7 µm), gearbox(10.5 to 1815 µm), left header (10.7 to 1312.2 µm), right header (10.2 to 936.4 µm) and seatback (10.8 to 1311.9 µm).

The particle density for equivalent diameter 10-100 µm was observed to be 9-12 particles/mm^2, whereas the number of particles with equivalent diameter >100 µm reduced significantly at all the locations (3-5 particles/mm^2). Sharp edges of straw have serious effects on the operator's eyes, throat and skin, and exposed body. Tractor or combine lacking operator encloser expose the operator to the dust and straw. Collected samples were categorized into three fractions; 10 – 20 µm (thoracic), 20 – 100 µm (Inhalable) and > 100 µm (wheat straw). The distribution shows (Fig 2) that the inhalable dust percentage was found highest (65-71%) at all workspace locations. Particle size greater than 100 µm (straw) was 21-29%, and thoracic particles constituted 6-8% of total particulate matters. With the continuous movement of wind along with the forward movement of combine, it is very difficult to predict pattern of wind direction. Therefore, a thrust of wind consisting of a dust particle is experienced by the operator continuously. These straw particles act as irritants in the presence of sweat in the peak summer when temperatures are above 40ºC. It was observed that straw concentration was extremely high, which resulted in irritation of skin and eyes and swelling of the operator's face. In the present study, the numbers of particles per unit surface area observed were 12, 10, 9, 10, 12, and 9/mm^2 at different points of the working zone. This relates to the number of particles that have the potential to stick to the operator's body. As per literature, the total surface area of the human body is 1.9 m^2 for adult males (Mosteller 1987). The surface area of hands, arms and face

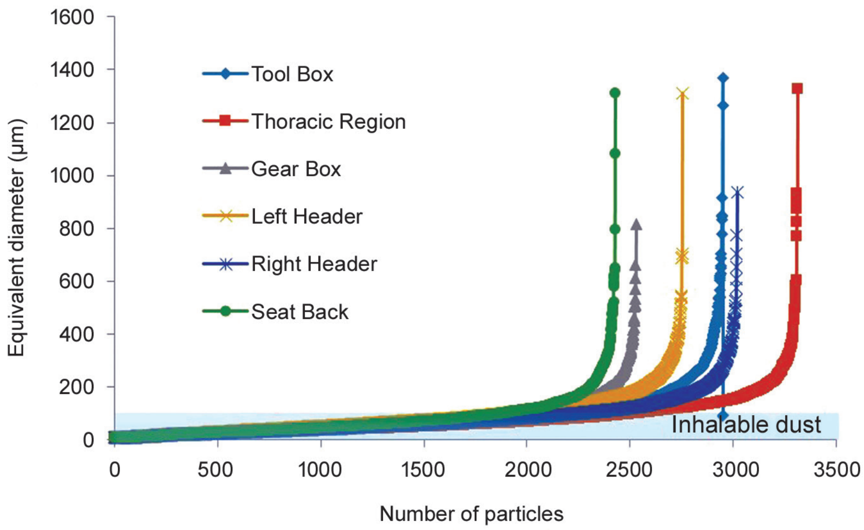

Fig 2 Distribution of equivalent diameter particles at different locations in the workspace.

Table 2 Mean dust concentration (μg/m^3)

Parameter	Breathing zone					
	PM_{10}	$PM_{2.5}$	$PM_{1.0}$	Inhalable	Thoracic	Alveolic
Mean	3722	453	120	9500	4150	940
Standard error	298.4	28.9	2.5	694.7	335.6	64.9
Standard deviation	8210.9	797.3	70.9	19116.2	9234.6	1788.2
Equivalent diameter of particles above 100 μm at operator workspace						
	Tool box	*Thoracic area*	*Gear box*	*Left header*	*Right header*	*Seat back*
Mean	76.4	76.2	60.1	73.0	72.6	56.1
Standard error	1.5	1.3	1.1	1.3	1.2	1.3
Standard deviations	92.5	75.4	68	77.2	77.2	79.6

is about 10% (~0.2 m^2); the conservative estimate of the number of particles that may stick (50%) on the skin are approximated to 1.2 million.

These particles also act as a medium for the movement of pollen, fungal spores, fungal hyphae, mycotoxins, bacteria and endotoxins (Spankie and Cherrie 2012). Common effects of dust particles were reported as coughing, postnasal drip, chest tightness and bronchitis. Some studies also indicate that farmers are more prone to respiratory problems than nonfarming communities (Malik 1986). Organic and inorganic both types of dust are generated during harvesting operation, causing allergic and non-allergic responses (Schenker 2000, Becklake *et al.* 2005). Ill effects on health may be due to the organic agents carried by dust (Swan *et al.* 2007). Studies have shown that exposure to grain dust may induce acute conjunctiva, nasal, respiratory, and systemic symptoms (Chan *et al.* 1980). A study from India showed that 22% of people suffer from respiratory problems among farmers (Behera *et al.* 2005), and any exposure to dust loaded with microorganisms can deteriorate the health status.

Statistical analysis: The probability density of mass concentration of different sizes of particulate matter (inhalable, <100 μm) was observed in the frequency density distribution. It was observed that all the particles with different mass concentrations tend to approach "Log-Normal distribution". Similarly, the equivalent diameter of particles above 100 μm also tends to follow "Log-Normal distribution" for particle size variation in a wide range of its diameter and adjust its shape. Particle equivalent diameter varied from 10 to 1400 μm (Fig 2). The observed mean, standard error and standard deviations of dust concentrations of PM_{10}, $PM_{2.5}$, $PM_{1.0}$, Inhalable, Thoracic and Alveolic in the breathing zone and equivalent diameter at different locations: Toolbox, Thoracic region, Gearbox, Left header, Right header, Seatback and are presented in Table 2.

Combine harvesting operation expose the operators to high concentrations of particulate matter. Average concentrations of PM_{10} and $PM_{2.5}$ were 3722 and 453 μg/m^3, respectively, which were many folds higher than the permissible limits both for an annual and daily basis. The particulate matter assessment indicated a wide range of variation in equivalent diameter (10-1400 μm) of wheat straw with a very high density of 8-12 particles per sq mm. Assuming the exposed body area of the operator (~0.2 m^2), the conservative estimate of the number of particles that may stick to the skin is 1.2 million. This indicates a high concentration of particulate matter in combine harvester operation to affect the operator's health adversely.

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