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Agricultural dust protective interventions for Indian farm workers

ASHUTOSH PANDIRWAR[1], ADARSH KUMAR[2], J K SINGH[3], INDRA MANI[4], S K JHA[5] and RAMASUBRAMANIAN V[6]

Indian Agricultural Research Institute, New Delhi 110 012.

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ABSTRACT

Magnitude of dust concentration in breathing zone in manual harvesting, and threshing operation of wheat crop were measured. The dust levels were 11.89, 4.67 and 3.20 mg/m^3 for in-halable, thoracic and respirable dusts respectively. Dust concentration was highest in breathing zone of the workers feeding the crop into thresher as compared to the workers engaged in harvesting with sickle, workers supplying crop to feeder and workers collecting threshed grains. The analysis of particle size distribution of dust indicated relatively low mass proportion of particles smaller than 2.5 μm and high percentage of particles over 7 μm diameters. Three types of dust filters, i.e. cloth, foam and non-woven fabric were selected and evaluated for filtration efficiency and pressure drop. An experimental setup was developed to measure filtration efficiency and pressure drop with varying filter area and dust concentration. The filtration efficiency of dust filters ranged from 50.76 to 59.71% (cloth), 89.19 to 92.78 % (foam) and 96.50 to 98.70 % (non-woven fabric) and pressure drop ranged from 5 to 17.83 (cloth), 23.83 to 38.50 (foam) and 14.17 to 27.67 (non-woven fabric) mm of H_2O for three different filter areas and dust concentrations, respectively. The results of subjective evaluation of dust protectors with field workers showed that, non-woven fabric was most preferred because of higher filtration efficiency and lower pressure drop. It was concluded that, non-woven fabric based dust protector provides the highest dust protection with lowest breathing resistance.

Key words : Breathing zone, Dust, Harvesting, Dust protector, Filter efficiency, Filter material, Pressure drop, Threshing, Threshold limits

Agricultural activities are performed in the potentially health risk environment due to exposure to high level of dust, atmospheric temperature, noise, vibration, chemical and biological agents. Dust exposure in agriculture, was recognized in the 16th century as a cause of respiratory disease, and is a major source of respiratory morbidity and mortality among agricultural workers (Schenker 2000). Dust is also generated in agricultural machine operations in the field because of machine-soil and machine-plant interactions. The agricultural workers inhale these dusts in course of normal breathing. Dusts generated in agricultural activities could be classified as inorganic dusts (soil/mineral dusts), organic dusts (plant debris), and biological dusts (animal debris). Dust sizes in the air could vary in the range of 1-30 μm (Alsan 1998). Dusts larger than 10 μm are considered to be coarse dusts, which are blocked in the upper air passages in the body. Dust particles smaller than 10 μm are fine dusts and can penetrate into lower air passages in the human body.

Agricultural activities are energy intensive operation, and therefore the farmer work at elevated heart rate, and increased respiration rate, which enhances inhaling of dusts at the workplace (Christensen *et al.* 1992). According to Reilly (1981), operators associated with agriculture activities faces allergies four times more as compared to a control group. Respiratory problems turned out to be the second most common diseases that the farmers suffer and tractor and combine operators experienced bronchioles two times more than other agricultural workers.

Berberet *et al.* (1998) studied the respirable dust and crystalline silica (quartz) exposure resulting from potato harvesting operations. The maximum respirable dust exposure was 5.05 mg/m^3, respirable silica 0.105 mg/m^3, and silica 12.85 per cent. Lee *et al.* (2004) determined the personal exposure to inorganic and organic dust during manual harvesting operations of California citrus and table grapes. Exposures for citrus harvest had 39.7 mg/m^3 and 1.14 mg/m^3 for inhalable and respirable dust respectively. These exposures exceeded the threshold limit value for inhalable and respirable dust.

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[2]Principal scientist (email: adarsh_iari@rediffmail.com); [3]Principal scientist (email: jksingh_engg@iari.res.in); [4]Principal scientist (email: maniindra99@gmail.com); [5]Principal scientist (email: skj_ageg@iari.res.in), Post Harvest Technology; [6]Senior scientist (email: ram_stat@yahoo.co.in), Division of Agricultural Statistics, IASRI, New Delhi 110012.

Dust may also cause poisoning and allergy in the respiratory tract (Witney 1988) and inflammation of the eyes, lungs, and the skin (Matthews and Knight 1971). Intoxicant dusts in the lower respiratory tract may cause farmers' lung disease, resulting in productivity loss, increased health costs and even death in severe cases (Erkan 1989). The severity of adverse effects of dust in terms of human health depends on the source of dust particles, particle sizes, dust concentration, and exposure time (Witney 1988). Therefore, particle sizes distributions and levels of dust concentration are critical factors. Moreover, use of protective gears by farmers indicated that when working with pesticides, only 44% of farmers wear gloves, 22% wear eye protection, 8% wear respiratory protection, and 4% wear coveralls (Murphy 2005).

Using respiratory protection can significantly reduce the risk of contracting serious lung diseases because of heavy dust concentration. The economical methods for protection of workers against the dust are personal dust protectors such as dust masks to provide protection against airborne dust particles, chaff, pollen, and non-toxic paint spray dusts.

The uses of dust protectors are being hampered by difficulty in breathing and communication. Morcos (1996) studied the performance of industrial bag filters to control particulate emissions. The pressure drop across the fabric and collected dust layer increased exponentially from 14 to 36 mm of water with increase of dust loading on the filter from 0 to 1300 g/m^2.

There are very few studies on filter efficiency of different materials used for personal dust protectors. Sumi and Araya (1996) tested an air filter consisting of cotton and artificial fibers; dust collection efficiency was 98% for particles larger than 50 micron, 86 to 89% for 20-30 micron particles, and 86% for particles finer than 10 micron. Burton *et al.* (2007) determined the physical collection efficiency of commercially available filters for collecting airborne bacteria, viruses, and other particles. The physical collection efficiency was determined by measuring particle concentrations size-selectively upstream and downstream of the filters. The PTFE (polytetrafluoroethylene) and gelatin filters showed excellent collection efficiency (>93%) for all of the test particles. Smigielski (2006) designed a setup for testing HEPA (High Efficiency Particulate Air) filter efficiency. A closed system "HEPA filter testing unit" was assembled consisting of a fan, industrial damper, two ducts, and filter housing. The concentrations of a challenge aerosol up-stream and down-stream were used to calculate the filters capture efficiency. Chhuneja (2009) assessed six different types of available personal dust protectors and used them for combine harvester operators for dust pollution. The filtration efficiency of the dust protectors varied from 65.5% (single tissue paper) to 92.2% (cloth). The dust protector of disposable cloth material was noted to have the highest acceptability during wheat as well as paddy harvesting. To understand the magnitude of dust concentrations in farm operations and identifying suitable cost effective filters, a study was undertaken to assess dust level in manual harvesting and threshing of wheat and develop dust protectors for farm workers.

MATERIAL AND METHODS

The study was conducted on the research fields of Indian Agricultural Research Institute, New Delhi (India). The soil of this region is medium textured. Wheat being the major cereal crop of the country occupies maximum area and involves a very large number of farm workers, so operations related to this crop was selected for the study. The measurements were taken during the peak season of harvesting and threshing of wheat, i.e. in April-May. Manual harvesting and threshing of wheat were selected for the studies. In these operations, the observation points selected for measurement were workers harvesting with sickle, workers feeding crop into thresher chute, workers supplying crop to feeder and workers collecting threshed grains after threshing operation. Threshers with hold on type feeding unit was selected for study as it creates high dust concentration as compared to throw in type thresher.

Samples collected included total dust, respirable dust, and thoracic dust from the breathing zone of the workers in the work environment. Sampling time taken was as 10 minutes. To characterize the exposure levels, numbers of air samples were collected. Dust concentration (mg/m^3) was measured using real - time personal dust monitor. Flow rate of the device was 1.5 - 2.3 l/m, sensing range varied between 0.01 and 200 mg/m^3 and its particle size range was 0.1 – 100 μm. A simple fixture for measurement was developed for personal dust monitor, which facilitated the access to breathing zone of workers.

Dust measurement for each field operation was done between 9 AM to 2 PM. A total of thirty-six measurements were taken for three dust categories (inhalable, thoracic and respirable) with three replications each for all the four operational locations. This study was conducted to characterize potential exposure during harvesting and threshing. Average values of environmental parameters such as temperature, wind velocity and relative humidity were also recorded at the time of experiment.

The particle size distribution of dust during selected operations was also recorded using air sampler measuring mass concentration for PM2.5 (Particulate matter), PM10 and TSP (Total suspended particulate) for two minutes of sampling time, based on the mass concentrations of dust particles in proportion of diameter less than 2.5, 10 and 25 μm.

The mass concentration of the particles for PM2.5 and PM10 was compared with standards recommended by Environmental Protection Agency (EPA, 2011) and National Ambient Air Quality Standards (2009) given by Central Pollution Control Board, New Delhi.

An experimental set-up consisting of dust chamber of size 65 cm × 65 cm × 65 cm as per BIS 9473: 1980 was fabricated. The frame of the chamber was made up of angle iron with sides 5 mm thick transparent acrylic sheet for visual observation of turbulence of air and dust dispersion in the chamber. A centrifugal blower with flow rate of 60 m^3/h was mounted at the bottom of the chamber with its outlet directed into chamber to create turbulence and distribute dust and air in the entire chamber. The outlet of chamber was connected to the inlet section of blower in order to achieve mass balance of dust. The filter assembly was fabricated and attached to one sidewall of the dust chamber. The filter material was sandwiched between upstream (Dust chamber side) and downstream (Dust monitor turbine side) and has the provision to vary the filter area. The filter assembly was made of airtight funnel shaped chamber with sensing head of real time personal dust monitor. The U-tube manometer was also used to measure the pressure drop during air filtration. One end of the manometer was fixed in the funnel wall at downstream side and other exposed to atmospheric pressure. A graduated wooden scale was also mounted along with manometer to measure the pressure difference. The experimental set up is shown in Fig 1.

Three filter materials namely cloth, foam and non-woven fabric, commonly used for the protection against solid aerosols in the disposable type masks, were selected for the study. The filter efficiency of selected dust protectors was determined for the wheat dust by measuring dust level on upstream and downstream side of filter material. A sampling time of three minutes was used for taking readings of dust levels in upstream and downstream sides.

In order to study the effect of filter area and dust levels on filtration performance and filter resistance, as expressed in terms of pressure drop, three filters of size 9 × 13, 10 × 14 and 11 × 15 cm^2 and three dust levels (20, 30 and 40 mg/m^3) were selected for the study. A known amount of dust was fed in the chamber to simulate pre-selected dust concentration. The upstream side dust concentration was kept constant. Each filter was tested for all the three dust levels and three filter areas at constant flow rate. The filter efficiency was calculated from upstream and downstream observations, whereas filter resistance was measured from pressure drop in U-tube manometer.

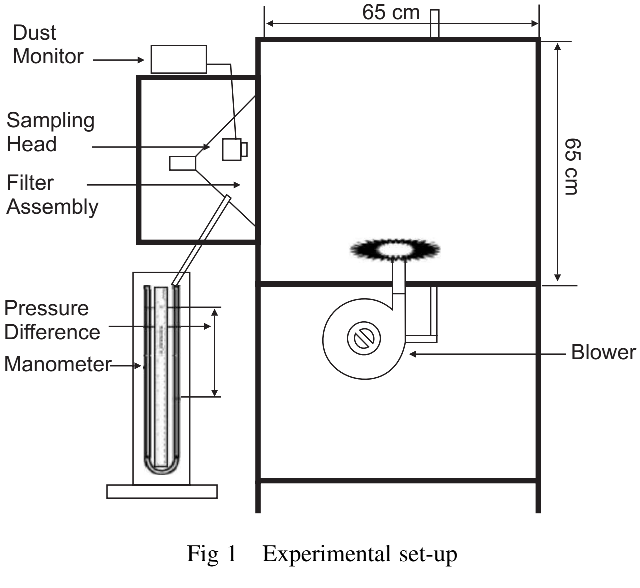


Fig 1 Experimental set-up

The personal dust protectors were developed from the selected filter materials. The design of dust protectors were such that they should completely cover the nose and mouth and provide adequate fitness on face to minimize inflow of dusty air from the edges. As per the test procedure mentioned in BIS 9473-1980, all the three dust protectors were subjected to suitability tests of one hour each on twenty workers (ten female and ten male workers between the age group 20 to 58 years) performing wheat harvesting and threshing operation during the harvesting season.

The suitability test consisted of seven performance indicators as observed by the operators. A proforma was designed to record different parameters to assess the suitability of dust protectors in terms of breathing resistance, dust filtration performance, air leakage from sides, feeling of tightness on face, rate of sweating, any verbal communication difficulty and wear and tear of dust protectors during use. Each of the performance indicators was further categorized into three levels; low, medium and high respectively, to tabulate performance and discomfort levels. After recording feedback for various performance indicators, each of the operators was asked to give a comparative rank to all the dust protectors as per his preference for acceptability. The comparative rank was converted to comparative acceptability score by giving weightage of “3” to rank one, “2” to rank two, “1” to rank three. Thus, total acceptability score was obtained for different dust protectors. Based on cumulative score, the filter material having minimum pressure drop (breathing resistance) from laboratory study and highest acceptability score of workers was selected as best material for continuous operations on Indian farm condition.

RESULTS AND DISCUSSION

Dust concentration, environmental parameters and particle size distribution

Observations on total dust concentration and fractional composition (inhalable, thoracic, respirable) during wheat harvesting and threshing operations are given in the Table 1. The ambient environmental parameters such as mean temperature, mean wind velocity and mean relative humidity were also recorded during the experiment.

During manual harvesting of wheat mean inhalable, thoracic and respirable dust concentrations were 2.00, 1.01 and 0.503 mg/m^3 respectively (Table 1). There was no study on dust measurement for wheat harvesting and threshing in

Table 1 Dust concentrations and environmental parameters during harvesting and threshing of wheat crop

Activity/ Location	Dust type	Concentration (mg/m^3) Average ± SD	Mean temp. (°C)	Mean wind velocity (km/h)	Mean relative humidity (%)
Workers harvesting	Inhalable	2.00 ± 0.41	38.57	6.40	20.33
	Thoracic	1.01 ± 0.28	38.80	6.70	17.00
	Respirable	0.50 ± 0.19	38.43	5.70	17.00
Workers feeding crop into chute	Inhalable	11.89 ± 0.12	41.73	4.37	30.33
	Thoracic	4.67 ± 1.41	42.00	4.30	31.00
	Respirable	3.20 ± 0.26	42.00	4.30	31.00
Workers giving crop to feeder	Inhalable	3.98 ± 2.05	36.40	5.23	22.67
	Thoracic	1.58 ± 0.39	40.27	4.37	28.33
	Respirable	0.81 ± 0.51	42.80	3.80	30.00
Workers collecting threshed grains at outlet	Inhalable	1.39 ± 0.08	42.00	7.80	24.00
	Thoracic	0.72 ± 0.07	36.67	4.77	27.33
	Respirable	0.37 ± 0.10	36.13	5.63	29.00

the literature surveyed but few studies have been reported on other field crops in developed countries on mechanized farms. Berberet *et al.* (1998) determined the respirable dust exposure in potato harvesting operations to be 5.05 mg/m^3.

In the threshing operation, the micro-environment of worker feeding crop into thresher chute, the dust concentration was found to be 11.89, 4.67 and 3.20 mg/m^3, respectively for inhalable, thoracic and respirable type (Table 1). Dust concentration was high in this operation, as large amount of crop material was handled in machine-crop interaction. Threshing drum rotating at high speed impacting fed crop for detachment of grain from plants and convert feed material into small size particles. The finer size particles escape threshing drum as dust and increase dust concentration in the vicinity. There are no studies on dust assessment of threshing operation; however, a few studies are reported on other farm operations. Aybek and Arslan (2007) observed mean dust concentrations of 137.9 mg/m^3, 83.6 mg/m^3, 80.3 mg/m^3 and 88.8 mg/m^3 for soil packing, furrowing, straw making, and baling respectively, on tractors with no cabin. Dust exposure of a similar crop interaction was bailing, where it was 88.8 mg/m^3, much higher than the dust levels of present study as mechanical operations with higher power machines cause more disturbances resulting in high dust values.

The workers who were handling the harvested crop material and carrying it from entire field to the threshing unit were found to have exposure levels of 3.98, 1.58 and 0.81 mg/m^3 for inhalable, thoracic and respirable fractions, respectively (Table 1). The dust exposure was found to be lower than the feeding point of thresher as there was no crop-machine interaction in this activity and workers were moving in field while the location of crop feeder was fixed resulting in buildup of dust concentration. On the other hand, at the grain outlet of thresher, the dust exposure was least among all the four activities. There was very little visible dust at this location. The direction of air current to facilitate grain-chaff separation was responsible to blow away dust from grain outlet location. The inhalable, thoracic and respirable fractions at this point were 1.39, 0.72 and 0.37 mg/m^3, respectively. At the outlet clean grains were discharged which were free from crop stalks and soil particles after sieving and blowing operation.

The results of the analysis of inhalable dust particles in the workplaces under study are summarized in Table 2 and Fig 2. In this table PM 2.5 indicates respirable fractions, PM 10 indicate thoracic fractions and total suspended particles (TSP) indicates inhalable fractions of dust. TSP was highest (9.99 mg/m^3) in the breathing zone of workers feeding crop into thresher chute and lowest (5.32 mg/m^3) in the breathing zone of worker collecting grain at thresher outlet.

The particle size distribution pattern shows that, the dust concentration for fine (PM2.5) and coarse (PM10) particulate matter for all the four operations exceeding the standard value of 24 hour PM2.5 standard of 0.035 mg/m^3 and PM10

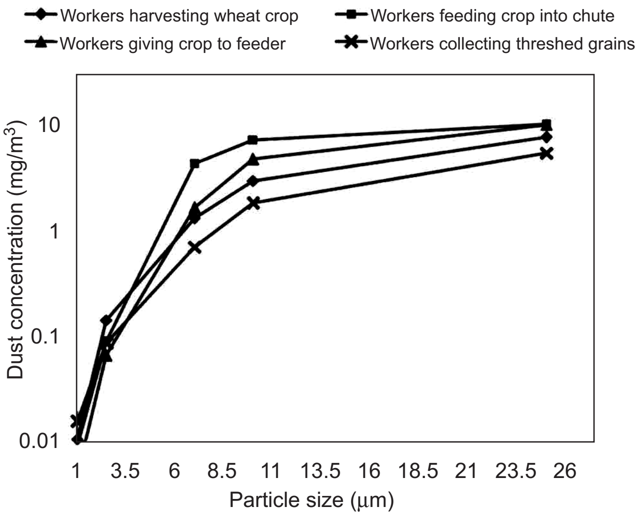


Fig 2 Particle size distribution of dust

Table 2 Particle size distribution of dust during harvesting and threshing

Activity	Dust concentration levels (mg/m^3) in different diameter intervals (µm)		
	PM 2.5 (<=2.5µm)	PM 10 (<= 10 µm)	TSP (<25 µm)
Worker harvesting crop	0.14	2.90	7.51
Workers feeding crop into chute	0.09	7.06	9.99
Workers giving crop to feeder	0.06	4.65	9.88
Workers collecting threshed grains at outlet	0.08	1.80	5.32
EPA standards	0.035	0.15	
National Ambient Air Qulity Standards	0.06	0.10	

standard of 0.15 mg/m^3 recommended by Environmental Protection Agency (EPA 2011). The size of particles is directly linked to their potential for causing health problems as these particles enter into lungs through the throat and nose. Once inhaled, these particles can affect the heart and lungs and cause serious health hazards.

Additionally, as per National Ambient Air Quality Standards (2009) given by Central Pollution Control Board, New Delhi, the observed particulate matter concentrations were beyond the standard limits of 0.10 and 0.06 mg/m^3 for PM10 and PM2.5 respectively. Nieuwenhuijsen *et al.* (1998) investigated exposure to dust and its particle size distribution in California agriculture. The largest proportion of dust belonged to the extra thoracic fraction (<PM10) and the levels of thoracic fraction for dust particles lie within the range of 3.6–26.5% of total dust in different agricultural operations. The author suggested that the percentage of these particles in total dust increases with an increase in dust exposure. Moreover, in this study, the proportion of extrathoracic and thoracic fraction fell within the range of 33.74 – 70.6% of total dust in different operations which are above the hazardous category of Air Quality Index (AQI).

It was observed that the workers performing threshing are potentially exposed to higher level of dust concentration exceeding the desirable limit (EPA, 2011). Study revealed that respirable particles (< 2.5 µm) and inhalable particles (<10µm) concentration in work environment of worker performing the task of harvesting, handling, threshing and collecting grains are exposed to hazardous level of dust concentration.

Effect of filter area and dust concentration on filter efficiency and pressure drop

All the three filter materials were tested in the developed experimental set-up for their efficiency and pressure drop. A known amount of wheat dust collected from field was fed into the chamber so as to simulate the desired dust concentrations. An average upstream dust concentration of 20.1, 29.1 and 40.47 mg/m^3 was achieved and kept constant during experiment. These concentrations levels were chosen on the basis of maximum instantaneous concentration found during the different field operations. Among all operational locations, the highest instantaneous dust concentration was 44 mg/m^3 on thresher platform (Fig 3). Filter materials were tested at each of these three dust concentrations levels for three selected filter areas 9 × 13 (A_1), 10 × 14 (A_2) and 11 × 15 (A_3) cm^2. Filter efficiency and pressure drops were recorded for each filter material at selected dust concentration

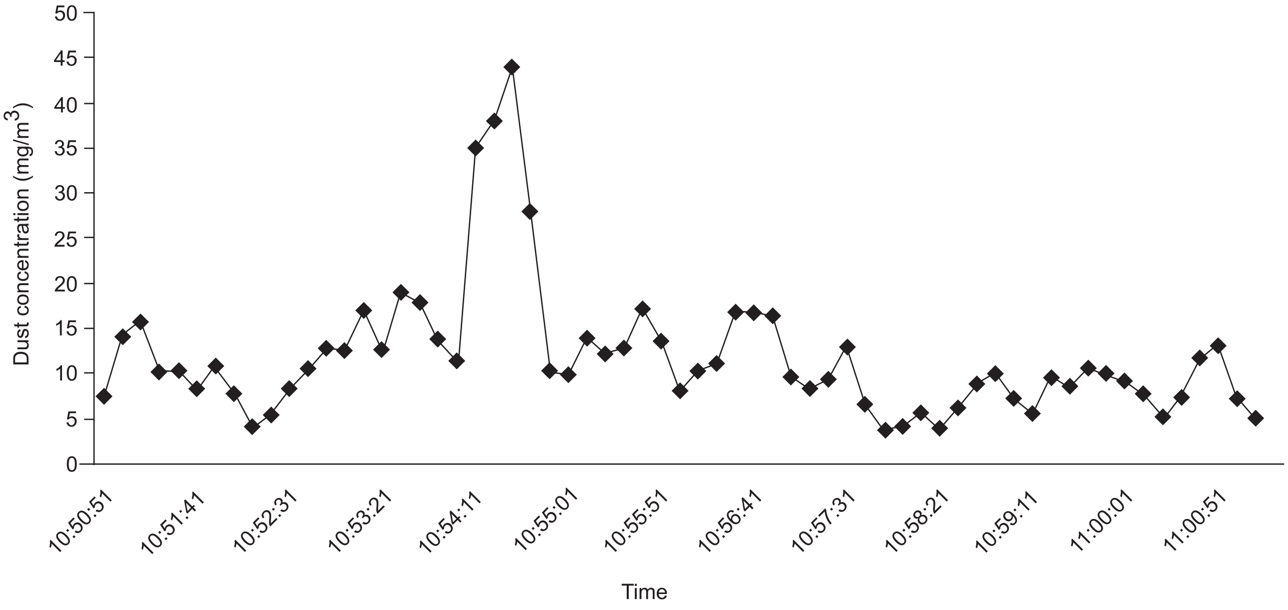


Fig 3 Instantaneous dust concentration during threshing for 10 minutes of time interval

Table 3 Effect of filter area on filter efficiency and pressure drop at different concentrations

Area	Filter materials efficiency (%), Pressure drop (mm of H_2O)					
	Cloth		Foam		Non-woven fabric	
	Efficiency (mean ± SD)	Pr. drop (mean ± SD)	Efficiency (mean ± SD)	Pr. drop (mean ± SD)	Efficiency (mean ± SD)	Pr. drop (mean ± SD)
	Dust concentration 20.1 mg/m³					
(A_1)	50.76±0.45	8.83±0.17	89.19±0.21	28.83±0.44	96.50±0.19	18.67±0.44
(A_2)	54.01±0.98	6.83±0.17	90.23±0.24	25.83±0.17	97.54±0.08	17.17±0.17
(A_3)	57.33±0.96	5.00±0.00	91.70±0.23	23.83±0.17	98.70±0.05	14.17±0.17
F-Cal	15.38**	198.50**	32.56**	76.00**	137.74**	63.00**
CD	2.95	0.48	0.81	1.02	0.33	1.02
CV (%)	2.68	3.42	0.44	1.92	0.17	3.00
	Dust concentration 29.1 mg/m³					
(A_1)	52.38±0.44	14.50±0.29	89.47±0.62	32.67±0.17	97.17±0.15	22.00±0.29
(A_2)	56.25±0.67	12.17±0.17	91.56±0.44	30.33±0.33	97.61±0.06	20.33±0.33
(A_3)	58.91±0.09	10.50 ±0.29	92.78±1.67	28.33±0.44	98.66±0.03	18.67±0.17
F-Cal	49.75**	62.29**	13.99**	42.33**	65.03**	37.50**
CD	1.64	0.90	1.58	1.18	0.33	0.96
CV (%)	1.44	3.56	0.85	1.90	0.17	2.318
	Dust concentration 40.47 mg/m³					
(A_1)	53.75±0.25	17.83±0.17	91.24±0.09	38.50±0.29	97.41±0.1	27.67±0.17
(A_2)	55.97±0.39	15.83±0.17	91.76±0.18	36.33±0.16	98.10±0.07	25.83±0.17
(A_3)	59.71±0.54	12.83±0.17	92.55±0.29	34.33±0.33	98.67±0.08	22.83±0.17
F-Cal	53.39**	228.00**	10.23*	58.62**	54.39**	214.33**
CD	1.45	0.59	0.73	0.96	0.30	0.58
CV (%)	1.26	1.86	0.39	1.29	0.15	1.13

** Significant at 1 % level of significance, * Significant at 5 % level of significance

and filter area for constant flow rate. The efficiency and pressure drop for all three filters at constant upstream concentrations and three filter areas are given in Table 3.

The results of ANOVA (Table 3) shows that the calculated F-values for filter efficiency and pressure drop in all three dust protectors and for all three dust loadings are higher than the table value for (2, 6) d.f. and at 1% level of significance. It means the results are significant, increase in filter area results in increase in filter efficiency and reduction in pressure drop.

The effect of filter area and dust concentration on filter efficiency and pressure drop is given in Table 3. For the cloth, the filter efficiency varied from 50.76 to 59.71% and pressure drop between 5 and 17.83 mm of H_2O, which was the lowest among all the filter materials tested. Filter efficiency of foam was high (89.19 to 92.78 %) as compared to cloth. The pressure drop across the foam varied from 23.83 to 38.50 mm of H_2O, higher than the permissible limit of 30.6 mm of water or 3 mbar (IS 8347: 2008). In case of non-woven fabric, the filter efficiency was very high (96.5 to 98.70 %) as compared to cloth and foam; pressure drop was 14.17 to 27.67 mm of H_2O which was lower as compared to foam but higher than cloth. It was found that with increase in filter area there was negligible increase in filter efficiency but higher reduction in pressure drop across the filter, which indicated reduction in breathing resistance. This increased efficiency and decrease in pressure drop with the increase in filter area was due to the fact that as the filter area increases total filter pore spaces also increases, which reduce the air flow velocity. The lower kinetic energy of dust particle allow particle to stick and settle down in flow channel of porous media. There are few studies on filter efficiency of different materials used for personal dust protectors. Sumi and Araya (1996) found high dust collection efficiency in an air filter made of cotton and artificial fibers. Dust collection efficiency was 98% for particles larger than 50 micron, 86 to 89% for 20-30 micron particles, and 86% for particles finer than 10 micron. In the present study also, the filters made of foam and non-woven fabrics for dust protection achieved efficiency of over 90 per cent.

The pore size of filter material has bearing on the size of dust particle which pass through it. In foam and non-woven cloth, the pore sizes are smaller than that of cloth which resulted in higher filter efficiency along with higher pressure drop, indicating higher breathing resistance. In the present study the characteristics of filter pores of the material had not been studied. However, it was also found that with the increase in the dust concentration from 20.1 to 29.1 and 40.47 mg/m^3, there was very small increment in the filter efficiency. This is due to the fact that, as the concentration increases more amount of dust is fed into the filter material and after some time filter pores gets clogged and restrict the transfer of dust towards downstream side, resulting in decreased rate of air exchange between upstream and downstream side, which in turn increases pressure drop across the filter. Nieuwenhuijsen *et al.* (1998) also reported that with increase in dust concentration extrathoracic fraction increases, leading to increased clogging of filter with increase in agricultural dust concentration. Morcos (1996) determined the pressure drop across the fabric, which increased exponentially from 14 to 36 mm of water with increase in dust loading from 0 to 1300 g/m^2. In the present study also, the pressure drop increased with the increase in the dust concentration.

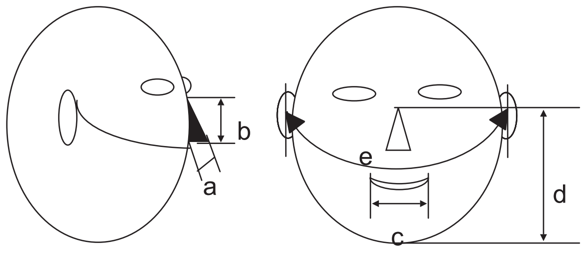
Development of dust protectors for subjective assessment

The dust protectors were developed using anthropometric data of twenty farm workers engaged on research farm. The shape of dust protectors was such that maximum surface area

Table 4 Workers feedback on different performance indicators

Performance indicator	Level	Dust protectors			Chi-square value (calculated)
		Cloth	Foam	Non woven fabric	
		Harvesting			
Breathing resistance	Low	18	13	17	7.15
	Medium	2	3	2	
	High	0	4	1	
Dust filtration performance	Low	4	0	0	9.60 *
	Medium	2	3	2	
	High	14	17	18	
Air leakage from sides	Low	18	12	17	5.88 *
	Medium	2	8	3	
	High	0	0	0	
Feeling of tightness on face	Low	17	16	18	0.79
	Medium	3	4	2	
	High	0	0	0	
Rate of sweating	Low	13	10	17	9.82 *
	Medium	7	7	2	
	High	0	3	1	
Wear and tear during use	Yes	1	3	3	1.47
	No	19	17	17	
Communication during use	Yes	20	16	20	9.37 **
	No	0	4	0	
		Threshing			
Breathing resistance	Low	19	12	16	8.80
	Medium	1	5	3	
	High	0	3	1	
Dust filtration performance	Low	3	0	0	10.12 *
	Medium	4	4	1	
	High	13	16	19	
Air leakage from sides	Low	15	10	16	7.46 *
	Medium	5	8	4	
	High	0	2	0	
Feeling of tightness on face	Low	17	16	18	2.01
	Medium	2	3	2	
	High	1	1	0	
Rate of sweating	Low	11	7	14	7.00
	Medium	9	12	5	
	High	0	1	1	
Wear and tear during use	Yes	6	4	5	0.53
	No	14	16	15	
Communication during use	Yes	20	18	20	2.87
	No	0	2	0	

** Significant at 1% level; * significant at 5% level



Anthropometric dimension	Size (mm)
Nose protrusion (a)	22
Subnasale sellion length (b)	48
Lip length (c)	52
Menton- sellion length (d)	110
Bitragion subnasale arc (e)	291

Fig 4 Anthropometric dimensions of face

for filtration can be achieved. Various face dimensions required to design dust protector are shown in the Fig. 4.

Suitability testing and comparative acceptability of dust protectors

The developed dust protectors (Fig. 5) were tested in field for their suitability to workers involved in wheat harvesting and threshing. The suitability test consisted of various performance indicators of dust protectors and feedback of workers were recorded (Table 4).

Likelihood chi-square test was performed to infer whether there is any association between a performance indicator and dust protectors. The calculated chi-square values obtained separately for each performance indicator shows that there is an association between performance indicator and dust protector as shown in Table 5.

Each of the workers was asked to give a comparative rank to all the dust protectors as per their preference for acceptability. The ranks given for preference of acceptability of dust protectors are given in Table 5. The comparative rank was converted to comparative acceptability score. Thus, the acceptability score was obtained for the selected dust protectors. The total acceptability score for all dust protectors during wheat harvesting and threshing season was calculated by summing them up as given in Table 5. The acceptability score was highest for dust protector fabricated by non-woven fabric followed by cloth and foam respectively.

Table 5 Acceptability rank and acceptability score of selected dust protectors

Operation	Rank	Frequency of ranks given by workers		
		Dust protectors		
		Cloth	Foam	Non woven fabric
Harvesting	1	3 (9)	2(6)	15(45)
	2	9(18)	8(16)	3(6)
	3	8(8)	10(10)	2(2)
Threshing	1	2(6)	2(6)	16(48)
	2	12(24)	5(10)	3(6)
	3	6(6)	13(13)	1(1)
Total (acceptability score)		40(71)	40(61)	40(108)

Score=rank frequency *weightage

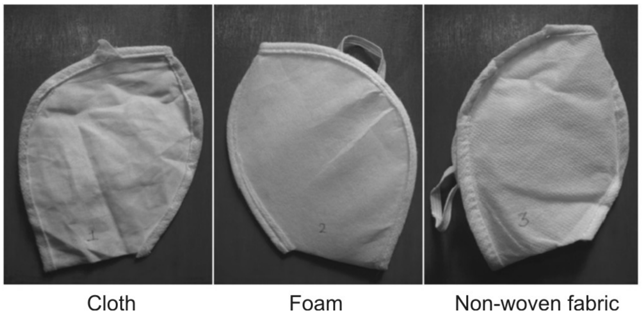

Cloth Foam Non-woven fabric

Fig 5 Developed personal dust protectors

Acceptability rank in parenthesis gives acceptability score. It is evident from the subjective assessment that, disposable dust protector of non-woven fabric has the highest acceptability score of 108 because of its high efficiency and low breathing resistance during wheat harvesting as well as threshing. The cloth type dust protectors ranked second because of less breathing resistance, though it had low filtration efficiency. The foam type dust protector, due to its high breathing difficulty had least acceptability among the workers. The cost of each unit of dust protector is Rs 4 which includes material and manufacturing cost.

It was found that, the workers performing threshing are potentially exposed to higher level of dust concentration exceeding the desirable limit. Study revealed that reparable particles (< 2.5 μm) and inhalable particles (<10 μm) concentration in work environment of worker performing the task of harvesting, handling, threshing and collecting grains are exposed to hazardous level of dust concentration. The personal dust protector should be provided to worker engaged in these activities to safeguard their health. It was also found that, as the filter area increased, pressure drop across the filter reduced. With the increase in the concentration there was very small increment in the filter efficiency and higher increment in pressure drop across the filter. The non-woven fabric material had higher filter efficiency (98.70 to 96.50%), lower pressure drop (14.17 to 27.67 mm of H_2O) and highest acceptability during the harvesting and threshing operation. Thus, non-woven fabric filter material can be used for personal dust protection of farm workers.

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