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ORIGINAL ARTICLE

Evaluation of personal protective equipments for dermal exposure pattern for pesticides during spraying

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ABSTRACT
The current agriculture yield extensively depends on pesticide consumption. The high yielding varieties of food grains increased the demand for pesticides; due to increase in plant diseases caused by pests, insects etc. Exposure to some pesticides, even in small doses, can immediately cause severe effects to humans. In tropical regions, it is reported that 88% of operators do not take any precautions during the time of pesticide application related activities because of discomfort in using personal protecting equipments and their expensive nature. The study was conducted to select and analyze commercially available personal protective equipments to assess their filtering capacity on different chemicals under laboratory as well as in field conditions. The selected aprons were evaluated on their comfort for operators during field spraying also the dermal deposition pattern was investigated.Six types of apron fabrics namely net cloth, stain guard cotton, cotton blend, Rexene, polyester and umbrella cloth were used to make the aprons to be used by spray operator. The penetration percentage for both chlorpyrifos and cypermethrin varied between 1.5% and 40%. The apron A5 and A6 performed very well for both chlorpyrifos and cypermethrin, where only 1.5% and 1.6% and 1.8% and 1.3% of the pesticide is penetrated through the fabrics, respectively. The penetration was found maximum for Apron A1, where nearly 40% of the chlorpyrifos and 34% of the cypermethrin penetrated through the fabric. Itwas observed that aprons A1 and A2 were rated with moderate comfort. Based on the study, among the selected fabrics apron A6 can be recommended as personal protection equipment for spraying operation. It exhibited 1.5% of pesticide penetration and a raise in temperature about 5.9% during 30 min spraying operation. Field experiments were conducted to observe the dermal exposure pattern of spray operator with lever operated knapsack sprayer and power mist blower. Maximum deposit of spray particles was found on lower half of the operator, where the legs, thighs and abdomen are most exposed to spray chemicals for both power mist blower and knapsack sprayer. The deposition amount was varied between 0.001 to 9.273 μl/cm² and 0.001 to 6.832 μl/cm² for power mist blower and knapsack sprayer, respectively. Thus it was recommended that the protective clothing should be fabricated to cover these areas effectively.
Keywords:*Dermal exposure, Personal protective equipments, Pesticides, Spray deposition.*

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INTRODUCTION

Agriculture is the predominant occupation for two third of the world population and majority of the population in India is engaged in agriculture. Currently, through-out the globe approximately 2 million tonnes of pesticides are utilized, out of which 47.5% are herbicides, 29.5% are insecticides, 17.5% are fungicides and 5.5% are other pesticides [9]. The top ten pesticide consuming countries in the world are China, the USA, Argentina, Thailand, Brazil, Italy, France, Canada, Japan and India. [29].Pesticide consumption in India was 59670 Metric tonnes during 2018-19 [2].In India pesticides are used extensively in crops such as cotton, paddy, chilies, horticulture and tobacco, etc. Pesticide residues are found in soil, air, subsurface water and ground water across the nation. However, little attention is given to their long term impact on the environment and human beings. Pesticide exposure is linked with various diseases including cancer, hormone disruption, asthma, allergies, and hypersensitivity [25]. A line of evidence also exists for the negative impacts of pesticide exposure leading to birth defects, reduced birth weight, fetal death, etc. [4, 18, 27].The majority of pesticides could affect the system by mechanisms including reduction of sperm counts and density, inhibition of spermatogenesis, sperm DNA damage, and increasing abnormal sperm morphology [19].

There are three exposure pathways in that the pesticide can enter into the human body: oral uptake, inhalation uptake and dermal absorption. It is quite well established that transdermal absorption through the skin can be the most important pathway for pesticides under typical field working conditions[26, 11, 16].About 97 per cent of human exposure to pesticides during spraying occurs through contact with skin[13, 5].

The use of Personal Protective Equipments (PPE) like coveralls, aprons, long pants and full sleeve shirts by the pesticide applicators protects their body from pesticide attack. Coveralls provide whole body protection; aprons protect the front portion of the body and, long pants and full sleeve shirts provide lower and upper body protection respectively. Other types of protective equipment are gloves to protect the hands, face masks to protect from inhalational exposure, and goggles for protection of eyes. Generally, Indian farmers dilute the chemical into a separate container and then mix the solution into the spray tank then spray with manually operated knapsack sprayer. Spraying is mostly done without protecting mouthnose and eyes. Although normal clothing can provide some protection, assuming it covers a major portion of the body it was found that the clothing may itself become contaminated and allows a continuing exposure. As a consequence, workers neglect to wear such clothing and thus suffers a high dermal exposure.The type of PPE used by the applicators varies from region to region. It was reported that 88% of the pesticide applicators at tropical regions do not take any precautions during the time of pesticide application related activities [7]. Feeling of discomfort in using PPE and their expensive nature are the reasons stated by them for such neglect [1]. Fabrics laminated or coated with plastic or rubber film provide excellent protection from exposure [23]. But there was problem with comfort and heat stress and indicated that cotton and cotton/polyester blends that was treated with flurochemical finishes showed great protection and comfort.

Effectiveness of personal protective equipment was studied on 15 pest control operators during mixing/loading and application of Chlorpyrifos [14]. They reported that actual dermal exposure levels decreased on average by fourfold after implementation of the PPE program.To evaluate the efficiency of two types of personal protective equipment (PPE), a study was conducted for potential dermal and respiratory exposure of the tractor driver during spraying in guava orchards with the air-assisted sprayer, The efficiency in the control of dermal exposure was 96.7 per cent: The feet, arms, thighs, front legs and back trunk were most exposed areas in the absence of protective measures [17]. Performance of different clothing types was studied for reducing skin exposure to five pesticides (azinphos-methyl, terbutylazine, alachlor, dimethoate and dicamba) in field by tractor equipped with boom sprayer [20]. They reported that the protection offered by personal protective equipment (PPE) was always more than 97 per cent, whereas the performance of cotton garments ranged from 84.1 to 92.5 per cent. The upper part of the body was the anatomical region showed the greatest values of the penetration factors. Commercially available masks were evaluated for their materials of construction, filtering efficiency and comfort while using in field (Modified Corlett and Bishop Scale) and breathing resistance [6]. For preventing endosulfan inhaling from air, masks with double layered poly propylene with water repellent quality filter was found better with an average filtering efficiency of 87%. Operator's opinion indicated that the mask made of flexible plastic with cotton filter and exhale valve gave an average wearing comfort and breathing comfort based on developed scale.

This study investigates the dermal exposure of agricultural operators by evaluating the commercially available personal protective equipments during pesticide spraying. The measurement of potential dermal exposure and inhalation of pesticides by the sprayer operator will provide vital information on the quantity of chemical substance that contaminates uncovered body regions and clothing worn by them and the chemical entering the respiratory system [12, 15]. Furthermore, it can be used as a base for estimating the risk involved in this activities. Based on that suitable protective devices can be developed or available devices modified to reduce the hazards of the spray operator.

MATERIAL AND METHODS

The commercially available six fabric materials were procured and evaluated for suitability as dermal protective equipment. Chlorpyriphos 20EC and Cypermetrin 25EC are the pesticides most commonly used to control different types of pests and diseases in crops [21]. Hence, these two pesticides were selected for the current investigation. The fabric materials were cleaned thoroughly in fresh water before using for experiment. For pesticide penetration an 8 cm square specimen of selected fabrics were cut and used as upper layer. The specimen was sandwiched together with an 8 cm square under layer of 100% absorbent cotton pad and a 12 cm square of aluminium foil placed directly beneath the cotton under layer to trap any formulation which passed through the under layer. A masking tape (2.5 cm wide) was placed over the outer 0.5 cm edge of the upper layer fabric and the 2 cm extension of the aluminium foil. The masking tape held the three layers securely together and prevented penetration of the pesticide to the under layer around the outside edge of the upper layer fabric. The specimens were placed horizontally on a table inside workshop laboratory. The table surface was cleaned thoroughly to avoid cross contamination of the fabric specimens.

Contamination of fabric specimens using pesticide formulation

The pipette method was used to measure percentage penetration through the 8x8 fabric specimens. The ISO 22608 standard was used to measure percentage penetration for each fabric. The specimens were contaminated by pipetting with a high performance micro volume pipettor 0.5 ml of the pesticide formulation prepared onto the center of the upper fabric layer, from a height of 2.5 cm [22].Although other procedures are used to simulate contamination which might occur through exposure to spray during pesticide application pipetting simulates a liquid spill or splash which may occur during mixing and loading or equipment repair. The contaminated specimens were dried horizontally for 2 hours, at room temperature. After drying the upper and under layers were separated by cutting around the inside edge of masking tape.

Determination of percentage of pesticide penetration through samples

The percentage of penetration though the upper layer of specimens was analyzed using gas chromatography. The analytical procedure for the pesticides Chlorpyrifos and cypermetrin are given below. An Agilent 7890A Gas Chromatograph (Agilent technologies, USA)equipped with sulphur/phosphorus flame photometric detector was used for the analysis. The chromatograph was equipped with a 30 m×320 μm×0.25 μm column and split/split less inlet. Each specimen was contaminated with 0.5 ml of field strength dilution of Chlorpyrifos (20% active ingredient). 25 ml of the concentrated formula was diluted with 75 ml distilled water. Thus each 100 ml of the diluted formula contained 5% a.i..The amount of chlorpyrifos which penetrated through the upper fabric to the under layer was calculated from the recorded charts of the gas chromatograph using the equation

$$\text{Mg pesticide} = \frac{\frac{A_s}{A_{std}} \times V_{std} \times \rho_{std}}{\frac{V_s}{\rho_s}} \times 1000$$

Where,

A_s = Peak area of the specimen

A_{std} = Peak area of the standard

V_{std}= Volume of standard injected, ml

V_s= Volume of specimen injected, ml

ρ_s = Concentration of standard, g/ml

ρ_{std}= Dilution factor of specimen, ml

Percentage of penetration

The amount of pesticide which penetrated through the upper layer to the under layer and was deposited on the under layer was expressed as a percentage of the total amount of pesticide formulation applied to the upper layer fabric.

$$\text{Penetration (\%)} = \frac{A_{un}}{At} \times 100$$

Where,

A_{un}= Amount of pesticide formulation (mg) extracted from under layer specimen

At = the amount of pesticide formulation (mg) extracted from 0.5 ml dilution delivered directly into a 250 ml conical flask

Subjective evaluation was carried out in the field to determine the wearing comfort of the aprons with six subjects.[8] was suitably modified and used to study the different comfort levels of the aprons[8].If any heat has built up in the body by wearing the aprons,it will be a discomfort for the operator. The temperature in the atmosphere as well as inside the apron was taken before starting operation and after 30 minutes of spraying operation.

Lever operated knapsack sprayer and power mist blower were selected for the dermal exposure study due to their wide acceptance among farmers. The experiment was conducted by keeping flow supply valve at 50 percent opening level for power mist blower. The experiment was repeated by keeping regulator valve at 1st, 2nd and 3rd positions (provided by the manufacturer). Methylene blue dye was used for preparing the spray solution for dermal exposure study. 2g of dye was added per liter of water and mixed thoroughly. This solution added to the tank of sprayer and applied in the field. The solution was tested for sufficient stickiness and colour made in the photo sheet prior to experiment.

Sampling method and field procedure

Exposure study was conducted only to the front area of the operator's body since most of the exposure was limited to front body area. Photo sheet was selected a material for spray deposit collection due to its sufficient thickness, less spreading of spray droplet and fast drying of deposited droplets. The photo sheets were attached to the operators clothing in the front area by demarcating different body parts (Arms, forearms, chest, abdomen, thighs and legs). The spray application time was 30 min at an application rate of 60-80 l/hr for lever operated knapsack sprayer and 180-250 l/hr for power mist blower under different settings. The photo sheets were scanned using a document scanner under 600 dpi setting. The scanned image was saved and analyzed using Deposit SCAN Software. The completly randomised statistical design was laid out to assess the protective performance of the six type of aprons tested under contamination by pesticide formulations of chlorpyrifos and cypermethrin.

RESULTS AND DISCUSSION

The specifications of the commercially available six fabric aprons used in the study are given in table 1. The percentage of penetration was determined for each apron fabric using pesticide formulations chlorpyrifos and cypermethrin and the results are furnished in table 2 and table 3, respectively.

Table 1 Specifications of the selected aprons

Apron No.	Material	Thickness (cm)	Area of dermal coverage (cm^2)	Fabric weight (g/m^2)
A1	Net cloth	0.012	4965	62.5
A2	Stain guard cotton	0.018	9320	36.4
A3	Rexene	0.033	4965	357.4
A4	Blends of cotton	0.025	4965	195
A5	Polyester	0.017	11040	46.8
A6	Umbrella Cloth	0.016	9320	38.6

Table 2 Percentage of penetration of 5% Chlorpyrifos through the selected apron fabrics

Sample	Peak area of the standard	Peak area of the specimen	Penetration	
			mg	Per cent (%)
0.5 ml of 5% Chlorpyrifos	13283.2	13169.3	11.153	
A1	11944.9	74406.7	4.374	39.4
A2	11793.8	55309.3	1.228	11.4
A3	12759.2	22397.5	0.634	6.1
A4	13033.3	25317.8	0.701	6.4
A5	12060.9	13533.1	0.161	1.5
A6	12040.7	14453.7	0.173	1.6

The fabrics were contaminated by 0.5 ml of 5% chlorpyrifos which contained 11.15 mg/l of a.i..The penetration percentage varied between 1.5 and 40%. For chlorpyrifos, apron A5 and A6 performed very well where only 1.5 and 1.6% of the pesticide was penetrated through the fabrics respectively. The penetration was found maximum for Apron A1 where nearly 40% of the chlorpyrifos penetrated through the fabric.

Table 3 Percentage of penetration of 5% Cypermethrin through the selected apronfabrics

Sample	Peak area of the standard	Peak area of the specimen	Penetration	
			mg	Per Cent (%)
0.5 ml of 5% Cypermethrin	25504.3	23351.4	6.263	
A1	23255.6	64283.7	2.099	33.2
A2	25359.0	48540.9	0.865	13.7
A3	26231.1	35099.7	0.424	6.7
A4	23434.5	37739.6	0.415	6.6
A5	23137.1	26421.3	0.113	1.8
A6	22927.3	24519.7	0.083	1.3

The fabrics were contaminated by 0.5 ml of 5% cypermethrin which contained 6.27 mg/l of a.i.The penetration percentage varied between 1.3 and 33.2%. For cypermethrin, apron A5 and A6 performed very well where only 1.8 and 1.3% of the pesticide was penetrated through the fabrics respectively. The penetration was found maximum for Apron A1 where nearly 34% of the cypermethrin penetrated through the fabric.Both experiments show that the pesticide type or formulations had no significant effect on penetration percentage of the apron fabrics. The apron A5 and A6 performed very well and medium performance was presented by Apron A3 and A4. A poor performance in resisting the pesticide penetration was presented by Apron A1 and A3. The fabric characteristics and fabric construction influenced the percentage of pesticide penetration.Similar results were obtained by [10], where laboratory evaluation of 12 different fabrics has determined that the non-woven fabrics provide best protection.

The results of trials on percentage of pesticide penetration were analyzed statistically using the complete randomized design and the analysis of variance for each fabric-pesticide combination is presented in table 4. Pesticide penetration was used as the response variable at the 95% confidence level. From the ANOVA table, it was observed that the type of apron affected the percentage of penetration significantly. This was obvious since each apron had different fabric characteristics and construction. The previous research data also supported the results obtained [17]. The type of pesticide had no significant effect of apron performance. Also the interaction between pesticide formulation and apron was not significant.

Table 4 ANOVA for percentage of pesticide penetration of apron fabrics

S No.	Source	DF	SS	MSS	F Ratio	Prob.
1	Aprons(A)	5	25698.456	5139.691	6.4258	0.014**
2	Pesticide(P)	1	4863.547	4863.547	11.4762	0.001 NS
3	A×P	5	2846.343	569.268	28.6594	0.000 NS
4	Error	24	428.695	17.862		
5	Total	35				

NS: Not Significant, CV:3.24%

Field evaluation of aprons

Aprons were evaluated for their thermal comfort and wearing comfort during spray operation for 30 min under field conditions. It was observed that the temperature in all the aprons has increased when compared to atmospheric temperature The temperature rise (%) in masks A1, A2, A3, A4, A5 and A6 were 5.2, 4.5, 5.8, 11.7, 10.3 and 5.9, respectively. According to the observations, cotton, net cloth, Rexene and umbrella cloth were selected for making of aprons.The wearing comforts of aprons were obtained by field subjective evaluation. Modified Corlett and Bishop Scale was used to indicate the comfort level for each apron (Table 5).

Table 5 Wearing comfort rating for aprons

S.No.	**Apron**	**Wearing Comfort Rating**	
		Points	**Comfort Level**
1	A1	7.16	Moderate Comfort
2	A2	8.0	Moderate Comfort
3	A3	6.5	Light Comfort
4	A4	6.33	Light Comfort
5	A5	2.58	Light discomfort
6	A6	6.33	Light Comfort

From the results it is observed that aprons A1 and A2 was rated with moderate comfort for wearing in field operation, this may be explained due to their light weight and fabric construction from cotton. Aprons A3, A4 and A6 were rated with light comfort, these aprons can also be recommended for field operation. Apron A5, made from polyester was rated with light discomfort with an average rating of 2.58 and also increased sweating and heat stress and thus it was not recommended as personal protection equipment in spraying.

Dermal deposition pattern during spraying

The field observations for dermal deposition pattern on different body parts during spraying by power mist blower and lever operated knapsack sprayer of subjects are presented table 6.It was observed that maximum deposit of spray particles was found on lower torso area of the operator for all three regulator valve settings of power mist blower, where legs, thighs and abdomen are more exposed to spray chemicals. Same pattern of deposition was reported by [3, 24].

Table 6 Dermal deposition pattern for Power mist blower and lever operated knapsack sprayer

Body part	Power mist blower						Lever operated knapsack sprayer	
	1st Setting		2nd Setting		3rd Setting			
	Deposits/cm²	Deposition (µl/cm²)	Deposits/cm²	Deposition (µl/cm²)	Deposits/cm²	Deposition (µl/cm²)	Deposits/cm²	Deposition (µL/cm²)
Arm(R)	0.5	0.003	0.5	0.001	0.2	0.004	0.1	0.001
Arm(L)	0.2	0.004	0.7	0.003	0.2	0.013	0.1	0.001
Fore Arm(R)	6.1	0.151	7.8	0.259	4.6	0.230	3.6	0.039
Fore Arm (L)	5.8	0.088	5.9	0.072	5.2	0.296	3.4	0.078
Chest	10.4	1.428	9.0	0.220	12.5	1.627	9.5	1.157
Abdomen	36.8	2.572	28.5	2.988	40.7	4.382	24.0	2.677
Thigh (R)	69.9	4.458	78.4	2.582	83.8	6.260	78.1	3.991
Thigh (L)	78.5	3.919	79.6	3.257	87.9	6.151	70.3	3.489
Leg (R)	84.5	5.703	93.4	9.331	96.8	9.239	83.1	6.832
Leg (L)	91.5	6.897	91.2	9.188	90.5	9.273	84.4	6.611

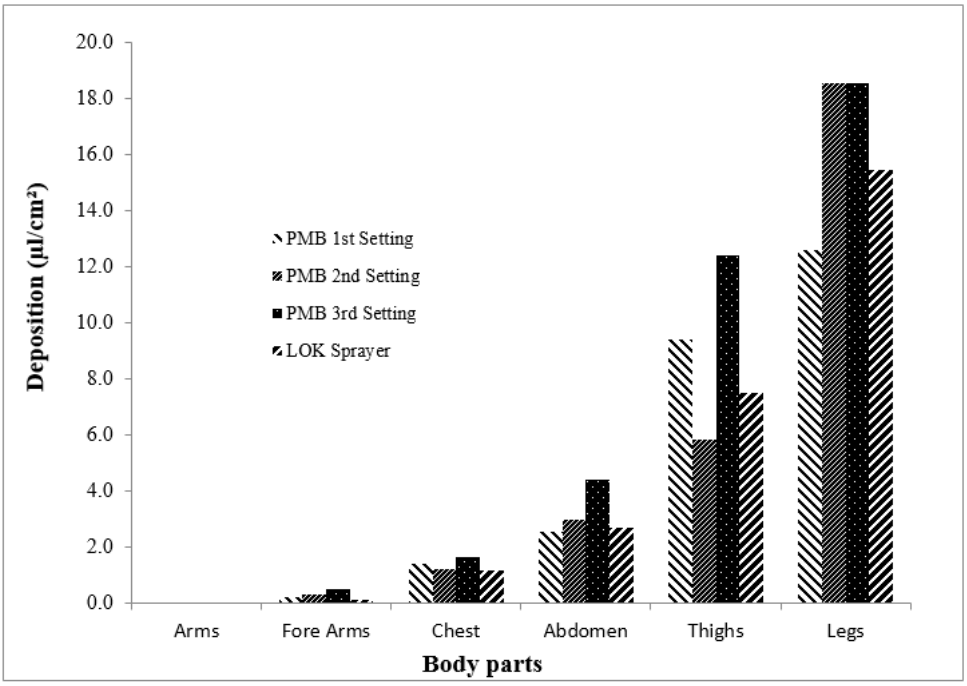

Figure 1 Spray deposits distribution on operator's body

The deposition amount was varied between 0.001 and 9.273µl/cm²in which maximum deposition was found on legs (5.7-9.27 µl/cm²). There was more exposure on the right half of the body for all cases. This is due to the fact that the operator holding the spray gun with his right hand and the sprayer's trigger handle and hose were constructed on the right side. The results of spray deposition pattern using a lever operated knapsack sprayer is also similar as observed in power mist blower where the maximum deposition of spray particles was found in lower torso area of the operators. Deposits per square cm were varied between 0.1 and 84.4.Deposition of spray liquid varied between 0.001 and 6.832 µl/cm² with maximum deposition on leg area (6.6-6.8 µl/cm²). A comparative study of dermal deposition pattern for the two sprayers is presented in figure 1. It was observed that the dermal deposition is progressively increasing on the lower regions of the body. Dermal deposition of chemicals on legs was highest during application due to both spray and drift deposition.

CONCLUSION

The present study was conducted to determine penetration percentage, thermal and wearing comfortand to evaluate dermal exposure pattern of chemicals viz.chlorpyrifos and cypermethrin on aprons made by six materials net cloth (A1), stain guard cotton (A2), Rexene (A3), cotton blend (A4), polyester (A5) and umbrella cloth (A6).Apron A1 had highest penetration per cent of 4.374 mg.Apron A5 and A6 performed very well for providing barrier to both the chemicals. Most of the subjects avoided wearing apron A5 (Polyester) due to increased sweating and heat stress. Apron A1, A2 were rated moderate comfort and minimum raise in temperature while operation in field but both failed as personal protection equipment since the percentage of penetration through the fabrics was more than 10%.Apron A6 can be recommended as personal protection equipment for spraying operation as it presented 1.5% of pesticide penetration and a raise in temperature about 5.9% during 30 min of spraying operation. Based on the Modified Corlett and Bhishop scale,apron A6 indicated light comfort (Score: 6.33) for wearing.Maximum dermal deposit was observed on lower half of the operator, mostly on legs during operation under both power mist blower (all three regulator valve settings) and knapsack sprayer.Thus it is recommended that the protective clothing should be fabricated to cover these areas effectively. Also, other practices such as washing the hands, changing farm clothing, and bathing immediately after spraying may help to reduce exposure.

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