Human-Centered Design Approach to Develop Personal Protective Equipment for Pesticide Applicators in India

Sunidhi Mehta and James McCay, West Virginia University

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Background

With the dawn of the Green Revolution, India's agricultural sector was introduced to novel irrigation techniques, chemical fertilizers, synthetic pesticides, and high-yielding varieties of crops (Mittal et al., 2014). It helped transform India from a food-deficit to a food-surplus nation. However, the unintended consequence of the Green Revolution was the overuse of pesticides, especially in the state of Punjab, considered the hub of the Green Revolution. While Punjab comprises only 1.5 percent of the landmass of India, it has one of the highest consumption rates of pesticides in the country (Tiwana et al., 2009). Pesticides are a complex mixture of biocidal chemicals that can potentially affect human health when absorbed in the body through dermal exposure, inhalation, or ingestion. They are often used to maintain high crop yields and product quality (Damalas & Eleftherohorinos 2011). Long-term exposure to these pesticides has been linked to many health issues such as cancer, Alzheimer's, and reproductive and neurodegenerative disorders. The United States Environmental Protection Agency (US EPA) mandates the use of certain personal protective equipment (PPE) while mixing, loading, and spraying pesticides in agricultural fields (US EPA, 2022). However, pesticide applicators in India rarely wear commercially available PPE (Bhattarai, 2016). This can be attributed to the fact that available PPE is not suitable for India's hot tropical weather, readily available and affordable for pesticide workers, and is not culturally acceptable. The purpose of this study was to design PPE for pesticide applicators in India that could be worn in tropical climates and was socially acceptable for the workers to wear.

Method

In this study, we used the multi-stage Human-Centered Design (HCD) approach to design two PPE ensembles for pesticide applicators in India. HCD considers the needs and perspectives of the individuals whom an item is being designed for instead of the designer's preferences (Giacomin, 2014). Therefore, using a 22-item questionnaire, we surveyed 120 pesticide applicators in a *pre-experimental study* to understand their current use of PPE, possible barriers, and motivations for PPE use while mixing, handling, and spraying pesticides. We then defined design specifications based on the data gathered from the pesticide applicators that would result in the PPE best protecting the wearer and being acceptable to them. Following the pre-experimental survey, we conducted a series of *experiments* to optimize the finish concentration

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for 100% cotton and 65/35% polyester/cotton (P/C) blended fabrics. The finish concentration was optimized based on the effect of the finish on fabrics' tensile strength and stiffness properties and optimum liquid-repellent performance. Unlike the traditional liquid-repellent finishes that release bio-accumulative toxins such as perfluorooctanoic acids (PFOA) and perfluoroalkyl substances (PFAS), we used a patented C_4 chemistry-based nano-coating called fluorochemical urethane to finish a 100% cotton and P/C blend fabrics. We *experimented* with several concentrations (50, 60, 70, 80, and 90 g/L) of fluorochemical urethane to develop a chemically protective nano-coating for 100% cotton and 65/35% P/C blended fabrics at an optimum concentration. The coating was applied to both fabrics using a pad-dry-cure method. We tested the impact of the nano-coating on the mechanical strength, stiffness, and air permeability of the fabrics and studied the laundering durability of the finish up to 30 laundering cycles. As a next step, we designed two PPE ensembles using the treated fabrics. We collected data on user acceptance of the PPE prototypes from 30 randomly selected pesticide workers. They were given a choice to wear each of the two PPE ensembles for one day while they conducted their routine field activities and shared their opinion on the overall design, thermal comfort, ease of movement, and social acceptance of the PPE ensembles.

Results and Discussion

The *pre-experimental survey* results indicated that most pesticide applicators did not wear PPE while spraying the pesticides and many carry out this operation with bare feet, hands, and torso exposing themselves to transdermal absorption of the harmful pesticides. The key findings from pre-experimental data included:

1. The main reasons for avoiding wearing commercially available PPE while working in the fields were the hot and humid climate, financial restrictions, and cultural barriers associated with wearing PPE.
2. About one-third of the pesticide applicators (33%) didn't read the pesticide labels before use, while roughly half (54%) read them but didn't follow the safety instructions. This can be attributed to the low literacy rates among pesticide applicators and the fact that instruction labels written in English are mostly illegible to the users.
3. The majority of the respondents (94%) stated that they shower immediately after the spray operation but only 72% of the respondents washed the contaminated clothing before reusing it.
4. The majority of the respondents (97.5%) mentioned drinking buttermilk, lemonade, or eating yogurt right before the spray operation. Their rationale was that the harmful effects of pesticide exposure could be minimized by consuming something sour before the spray operation. They also indicated applying mustard oil as a protective layer on the entire body before spraying pesticides in the field.

Our *experiments* found that 80 gm/L and 60 gm/L of fluorochemical urethane are the optimum finish concentrations for cotton and P/C blended fabrics respectively to ensure the fabrics had the

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proper mechanical strength, stiffness, and air permeability. A PPE ensemble was constructed using each of the nano-coated fabrics. The ensembles have various functional design features such as a hood, *kurta*/tunic, a pair of pants, and gloves constructed with nano-coated cotton and P/C blend fabrics based on the survey results. The two ensembles were identical except for the fabric. In the *post-experimental survey,* the majority of the Pesticide applicators ranked the PPE ensemble made with cotton fabric significantly higher ($P<0.005$) than the PPE made with P/C blended fabric in terms of perceived thermal comfort, ease of movement, and overall likeness of the design.

Conclusions and Implications

Proper use of PPE can significantly increase the protection of pesticide applicators. However, field observations show that PPE usage does not meet recommendations (Andrade-Rivas & Rother, 2015; Bakhsh et al., 2017; Bondori et al., 2018; Coffman et al., 2009; Damalas & Abdollahzadeh, 2016; DellaValle et al., 2012) due to factors such as cost of PPE, climatic conditions, lack of awareness, cultural barriers, and low levels of literacy in pesticide applicators in India. This study showed that PPE made from breathable fabrics such as cotton and a cotton/polyester blend and treated with a liquid-repellent nanocoating can offer a solution to these issues. To further solve the issue of noncompliance with PPE usage, a multifront approach including the collective effort of government, pesticide manufacturers, suppliers, extension service agents, and employers must be taken. Using the HCD approach to develop PPE may be an effective way of helping users understand the importance of PPE in reducing pesticide exposure and safeguarding their health.

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