How to protect agricultural workers from exposure to pesticides: Effectiveness of woven and natural resin-coated fabrics

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Abstract: Agricultural workers in low and middle-income countries usually wear their everyday clothing made of woven fabrics during pesticide application. Different characteristics of various woven fabrics have different abilities to prevent the penetration of pesticides through to the skin. Therefore, the ultimate goal of this study is that agricultural workers in Thailand can choose a suitable fabric of protective clothing to protect themselves from pesticide exposure. This study aims to investigate pesticide penetration levels in different woven fabrics, and to explore factors affecting levels of pesticide penetration through fabrics. In addition, our study aims to produce cotton fabrics coated with a natural resin to obtain water-repellent characteristics and evaluate their effectiveness in protecting against pesticides. Four pesticides used in the testing process were chlorpyrifos, cypermethrin, paraquat, and glyphosate. The results found that a suitable fabric to protect agricultural workers from pesticide exposure is a fabric which made of 100% cotton and have greater weight. With regard to natural resin-coated fabrics, fabric C1-R showed the highest levels of effectiveness in protecting against the pesticides (range between 89%-95%). The natural resin-coated fabric is an alternative fabric in the protection against pesticides for agricultural workers in low and middle-income countries when commercial PPE are prohibitively expensive.

Subjects: Agriculture & Environmental Sciences; Environment & Health; Environmental Change & Pollution

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PUBLIC INTEREST STATEMENT

Agricultural workers in low and middle-income countries usually wear their everyday clothing made of woven fabrics during pesticide application. Therefore, the ultimate goal of this study is that agricultural workers in Thailand can choose a suitable fabric of protective clothing to protect themselves from pesticide exposure. The results suggest that a suitable fabric to protect agricultural workers from pesticide exposure is a fabric which made of 100% cotton and have greater weight. In addition, the natural resin-coated fabric is an alternative fabric in the protection against pesticides for agricultural workers in low and middle-income countries when commercial PPE are prohibitively expensive.
Keywords: personal protective equipment; pesticides; protective clothing; pesticide exposure; water repellence

1. Introduction

Previous studies have shown that occupational exposure to pesticides is associated with an increased risk of acute and chronic health effects, which include cancers (K.H. Kim et al., 2017; Kaur & Kaur, 2018; Sapbamrer & Nata, 2014). It has been shown that agricultural workers are more vulnerable than typical non-agricultural workers because they face a greater risk of exposure to pesticides (Damalas & Koutroubas, 2010). Chlorpyrifos and cypermethrin are routinely used as insecticides in agriculture, while paraquat and glyphosate are widely used as herbicides, especially in Southeast Asian countries including Thailand (Gupta, 2012; Sapbamrer, 2018; Tawatsin et al., 2015). Pesticide exposure occurs mainly during mixing, loading and application. The workers who carry out these activities can be exposed to pesticides as a result of spliss and splashes, and also due to direct contact with the spray. Therefore, the main routes of exposure are dermal contact and inhalation (Damalas & Koutroubas, 2016; Gupta, 2012; Miguelino, 2014).

Pesticides in liquid formulation can attribute to greater dermal exposure (Damalas and Eleftherohorinios, 2011). Therefore, personal protective clothing plays an important role in protecting agricultural workers from being exposed to pesticides through the skin while handling them. Coveralls made of polyvinyl chloride (PVC), butyl rubber, or neoprene confer high levels of protection (Oregon OSHA, 2019). Available studies suggested that wearing a Category III type 3 partial body gown (Tychem® F Gown style) had a protective effect of 98.7%, and wearing Tyvek coveralls had a protective effect higher than 97% (Protano et al., 2009; Thouvenin et al., 2017). However, these garments impede heat exchange by sweat evaporation, causing discomfort and potentially serious heat stress under hot and humid conditions. In addition, these types of clothing are quite expensive, only single use (disposa1), and difficult to find, meaning the poor workers cannot purchase them (Holmér, 2006; Jallow et al., 2017; Sapbamrer, 2018). Department of Disease Control, Ministry of Public Health, Thailand, recommended that agricultural workers should wear long-sleeved shirts and long-sleeved trousers made of waterproof cloth (Department of Disease Control, Ministry of Public Health, Thailand, 2010). In practice, many agricultural workers wear their everyday clothing made of woven fabrics during pesticide handling because of its comfort and low cost (Sapbamrer, 2018). As we surveyed, the woven fabrics commonly worn by Thai agricultural workers are usually made of cotton, polyester, and a cotton/polyester blend. Different characteristics of various woven fabrics have different abilities prevent the penetration of chemicals through to the skin (Lee & Obendorf, 2005; Miguelino, 2014; Shaw & Schiffelbein, 2016a). A laboratory study by Jain and Raheel (2003) also mentioned that the penetration of atrazine and pendimethalin ranged from 22.88% to 84.74% for 100% cotton, 51.8–84.8% for polyester, and 68.2–88.9% for cotton/polyester blend. Similarly, a laboratory study by Zhang and Raheel (2003) also mentioned that the penetration of atrazine and pendimethalin ranged from 11.8% to 66.9% for 100% cotton and 15.2–65.8% for cotton/polyester blend. Therefore, it is reasonable to propose that if agricultural workers wear aggressive clothing made of suitable woven fabrics a balance between risk from pesticide exposure and comfort of the workers could be achieved.

Factors associated with the exposure risk of pesticides are the type of chemical involved, concentration of the chemicals, chemical composition, and time of exposure to chemicals. Fabric factors include type of fabric, thickness, fabric weight, bound or seal seam, yarn twist and wicking, waterproof characteristics of fabrics, and design features (Macfarlane et al., 2013; Miguelino, 2014; Shaw & Schiffelbein, 2016a). Water repellence is also a crucial factor in the protection against pesticide exposure. Low penetration levels through the fabric were found in woven fabric that was treated with repellent finishes due to its repellence property. A water-repellent coating can protect against fine spray particles and small liquid splashes and stop them penetrating the clothing (Das et al., 2016; Rahman Bhuiyan et al., 2019). Natural resin-coated fabric is an alternative fabric for protection against pesticides because of its water-repellent characteristics, simple manufacturing process, raw material availability, low cost, and breathability. We expected that a cotton fabric
that is coated with natural resin would give protection against pesticides and feel comfortable whilst working in a tropical climate at the same time.

In view of the above, the aim of this study is to investigate the level of pesticide penetration in different woven fabrics, to identify the fabric that has the lowest % of pesticide penetration, and to explore factors affecting pesticide penetration through fabrics. In addition, our study aims to produce cotton fabrics coated with natural resin to obtain water-repellent characteristics and evaluate their effectiveness in protecting against pesticides. The four pesticides used in the tests were chlorpyrifos, cypermethrin, paraquat, and glyphosate because these pesticides are routinely and widely used in Southeast Asia. An ultimate goal is that knowledge from this study can be integrated into environmental health aspects. Agricultural workers can choose a suitable fabric of protective clothing to protect themselves from exposure to pesticides, leading to good health and well-being in agricultural workers.

2. Methods
The study was conducted in two parts. Part 1: Effectiveness of different woven fabrics in protecting against exposure to pesticides, and Part 2: Effectiveness of natural resin-coated fabrics in protecting against exposure to pesticides.

2.1. Types of fabrics
In order to obtain various types of woven fabrics commercially available and used by agricultural workers, the researchers collected the fabrics from various sources in Thailand. Sixteen woven fabrics were selected. Of these 16 fabrics, seven fabrics were classified as 100% cotton (fabrics labelled C1-C7), six were a cotton/polyester blend (fabrics CP1-CP6), and three were 100% polyester (fabrics P1-P3).

Nine fabrics were selected which had a cotton component higher than 50% and in order to ensure water-repellent fabrics were coated with natural resin. These fabrics included fabrics C1, C2, C3, C4, C5, C6, C7, CP1, and CP2. Overall, a total of 25 woven fabrics (16 commercially available fabrics and nine resin-coated fabrics) were tested. Before testing for pesticide penetration, fabrics were laundered in an automatic washing machine (Samsung, WA13F533QRVST 13 kg) with 200 mL of a commercially available detergent for 45 minutes. The fabric samples were rinsed with tap water and air-dried under ambient conditions. The properties of woven fabrics and natural resin-coated fabrics are shown in Table 1. The thickness of each fabric was measured in accordance with ASTM D 1777–96, and fabric weight was measured to ASTM D 3776–96 standard (Option C).

2.2. Coating of cotton/cotton blend fabrics with natural resin
We produced natural resin-coated fabrics and tested their efficacy in protecting against pesticides. As the resin-coated fabrics display water resistance for longer than 24 hours and at a contact angle of water repellency greater than 120° (Figure 1). The process of coating is practical, uncomplicated, and is not hazardous to the environment. The coating process was done following the method described by Manoch Naksata and Vimol Naksata (Petty Patent no.7450, 8 July 2010, Thailand) (National Science and Technology Development Agency (NSTDA), 2016). First, the fabrics were cleaned with commercially available detergent and dried at 60–80 °C. Then, gum rosin (Chemwinfo Co., Ltd, Thailand) were melt into resin solution. The fabrics were soaked with the resin solution 1–3%w/v (M/L = 1:20) for 15 minutes, and potassium aluminum sulfate1-3%w/v (M/L = 1:20) (World Chemical Co., Ltd, Thailand) for 15 minutes. Finally, the fabrics were spin-dried at 3,000 cycles per minute for 3 minutes and dried at 60–80 °C. We produced the coated fabric in the Laboratory of the Department of Physics and Material Science, Faculty of Science, Chiang Mai University.

2.3. Test chemicals
Four commercially available pesticides widely used in agriculture were used for the study. These included chlorpyrifos 40%w/v-emulsifiable concentrate (ICP Ladda Co., Ltd, Thailand), cypermethrin 35%w/v-emulsifiable concentrate (Pato Chemical Co., Ltd, Thailand), paraquat 27.6%w/v-water
Table 1. Property of woven fabrics and natural resin-coated fabric

| Code | Trade name of fabric | Fabric content | Fabric construction | Weight (g/m²) | Thickness (mm) | Water repellence |
|------|----------------------|----------------|---------------------|---------------|----------------|------------------|
| C1   | West Point           | 100% Cotton    | Twill weave         | 306.7 ± 0.6   | 0.624 ± 0.007  | No               |
| C2   | Denim                | 100% Cotton    | Twill weave         | 243.3 ± 2.5   | 0.643 ± 0.011  | No               |
| C3   | Chin Mai             | 100% Cotton    | Plain weave         | 234.7 ± 0.6   | 0.753 ± 0.024  | No               |
| C4   | Bamboo               | 100% Cotton    | Plain weave         | 170.3 ± 0.6   | 0.662 ± 0.027  | No               |
| C5   | Greige Cotton        | 100% Cotton    | Plain weave         | 190 ± 1.0     | 0.559 ± 0.021  | Yes              |
| C6   | Cotton no.32         | 100% Cotton    | Plain weave         | 146.3 ± 0.6   | 0.364 ± 0.003  | No               |
| C7   | Cotton No.40         | 100% Cotton    | Plain weave         | 134.3 ± 1.2   | 0.306 ± 0.009  | No               |
| CP1  | Greige TC            | Cotton/Polyester| Plain weave       | 199.7 ± 1.2   | 0.551 ± 0.009  | No               |
| CP2  | Oxford               | Cotton/Polyester| Plain weave       | 145.3 ± 0.6   | 0.306 ± 0.004  | No               |
| CP3  | Gabardine            | Cotton/Polyester| Plain weave       | 274.7 ± 1.2   | 0.634 ± 0.007  | No               |
| CP4  | Serge                | Cotton/Polyester| Plain weave       | 250.3 ± 1.5   | 0.394 ± 0.003  | No               |
| CP5  | Combtwill            | Cotton/Polyester| Twill weave        | 129.7 ± 0.6   | 0.235 ± 0.004  | No               |
| CP6  | Tore                 | Cotton/Polyester| Plain weave       | 117.3 ± 1.2   | 0.227 ± 0.010  | No               |
| P1   | PE                   | 100% Polyester  | Plain weave        | 175.7 ± 1.2   | 0.479 ± 0.004  | No               |
| P2   | DY                   | 100% Polyester  | Twill weave        | 195.3 ± 0.6   | 0.472 ± 0.002  | No               |
| P3   | Solon                | 100% Polyester  | Twill weave        | 150.7 ± 0.6   | 0.438 ± 0.005  | No               |

Natural resin-coated fabrics (9) *

| Code | Trade name of fabric | Fabric content | Fabric construction | Weight (g/m²) | Thickness (mm) | Water repellence |
|------|----------------------|----------------|---------------------|---------------|----------------|------------------|
| C1-R | West Point-R         | 100% Cotton    | Twill weave         | 312 ± 1.0     | 0.636 ± 0.005  | Yes              |
| C2-R | Denim-R              | 100% Cotton    | Twill weave         | 260.7 ± 0.6   | 0.650 ± 0.007  | Yes              |
| C3-R | Chin Mai-R           | 100% Cotton    | Plain weave         | 239.7 ± 0.6   | 0.769 ± 0.022  | Yes              |
| C4-R | Bamboo-R             | 100% Cotton    | Plain weave         | 178 ± 1.0     | 0.728 ± 0.013  | Yes              |
| C5-R | Greige Cotton-R      | 100% Cotton    | Plain weave         | 196.3 ± 0.6   | 0.567 ± 0.019  | Yes              |
| C6-R | Cotton no.32-R       | 100% Cotton    | Plain weave         | 152 ± 1.0     | 0.377 ± 0.003  | Yes              |

(Continued)
| Code | Trade name of fabric | Fabric content | Fabric construction | Weight (g/m²) | Thickness (mm) | Water repellence |
|------|----------------------|----------------|--------------------|--------------|----------------|-----------------|
| C7-R | Cotton No.40-R       | 100% Cotton    | Plain weave        | 140.3 ± 0.6  | 0.317 ± 0.005  | Yes             |
| CP1-R| Greige TC-R          | Cotton/Polyester| Plain weave        | 203.3 ± 1.2  | 0.564 ± 0.011  | Yes             |
| CP2-R| Oxford-R             | Cotton/Polyester| Plain weave        | 146.3 ± 0.6  | 0.322 ± 0.008  | Yes             |

*Woven fabrics which can be coated with resin solution should have a cotton component greater than 50%, therefore nine woven cotton and cotton blend fabrics were chosen to finish with resin solution; R = coated with rosin solution; C = 100% Cotton; CP = Cotton/Polyester blend; P = 100% Polyester*
soluble concentrate (Syngenta Crop Production Co., Ltd, Thailand), and glyphosate with surfactant 48%w/v-water soluble concentrate (Monsanto, Thailand).

The pesticides were diluted according to the advisory labeling on the pesticides. The test for the diluted pesticide represents the penetration of the application of pesticides due to spraying and/or other handling activities. The formulations were diluted to the final concentration of 2 mL/L of water for chlorpyrifos, 2 mL/L for cypermethrin, 8.3 mL/L for paraquat, and 10 mL/L for glyphosate (Table 2).

### 2.4. Measurement of pesticide penetration
Measurement of pesticide penetration through the fabrics was carried out by gravimetric methods according to the ISO22608 standard (Method A-high level of liquid formulation). Three layers of testing, including an 8 × 8 cm fabric specimen, an 8 × 8 cm absorbent layer, and an 8 × 8 cm collector layer, were weighed before testing. A fabric specimen and a collector layer were held together between an acrylic base plate and a cover plate. The 0.2 mL of each test pesticide was placed onto the center of the fabric specimen using a pipette. After 10 minutes, an absorbent layer was placed on the top of fabric specimen for 2 minutes (Figure 2). Finally, the three layers were re-weighed. Six replicates were carried out for each fabric and test pesticide. The formula used for calculation of the percentage (%) of penetration was as follows:

Table 2. Characteristics of pesticide formulations

| Formulation        | Active ingredient          | Type of pesticides | Formulation type                                      | Dilute formulation       |
|--------------------|----------------------------|--------------------|-------------------------------------------------------|--------------------------|
| Cosmic40           | Chlorpyrifos               | Insecticide        | 40% w/v-Emulsifiable concentrate                       | 2 mL/L of water          |
| Thaiperthroid35    | Cypermethrin               | Insecticide        | 35% w/v-Emulsifiable concentrate                       | 2 mL/L of water          |
| Gramoxone®         | Paraquat dichloride        | Herbicide          | 27.6% w/v-Water soluble concentrate                    | 8.3 mL/L 1 L of water    |
| Roundup®           | Glyphosate isopropylammonium| Herbicide          | 48% w/v-Water soluble concentrate with surfactant     | 10 mL/L 1 L of water     |

Figure 1. Water repellence characteristic of natural resin-coated fabric.
Penetration = $\frac{M_p \times 100}{M_t}$

Where,

$M_p$ = mass (g) of test liquid in the collector layer

$M_t$ = total mass (g) of test liquid

2.5. Data analysis

Descriptive statistics, such as mean and standard deviation, were analyzed. A one-way ANOVA was used to compare the difference in % penetration level of the 16 woven fabrics for each pesticide. Multiple linear regression analysis was used to explore factors affecting pesticide penetration through fabrics. Post Hoc test was used to compare the % penetration among 16 woven fabrics. An independent t-test was used to compare the % penetration between natural resin-coated fabrics and un-coated fabrics. Significance level was set at $P$ value < 0.05.

3. Results

3.1. Part 1: effectiveness of different woven fabrics in protecting against exposure to pesticides

Levels of pesticide penetration through 16 woven fabrics are presented in Figure 3. These conditions represent the penetration of pesticides due to exposure from spraying and/or other handling. The lowest % of penetration for all pesticides tested was found in fabric C1 (23.4% for chlorpyrifos, 21.6% for cypermethrin, 21.5% for paraquat, and 21.4% for glyphosate). When performing a multifactorial analysis with a one-way ANOVA, fabric C1 had the lowest % of penetration for all pesticides at a statistical significance level of 0.05, when compared with other fabrics. The factors associated with diluted pesticide penetration were fabric content ($B \pm SE = -18.142 \pm 0.730$, 95%CI = -19.577, -16.708), chemical type (8...
Figure 3. Levels of pesticide penetration through different woven fabrics.

* = The lowest % of pesticide penetration at a statistical significance level of 0.05

** = The lowest % of pesticide penetration at a statistical significance level of 0.01

| Parameters | Beta  | SE   | 95%CI       |
|------------|-------|------|-------------|
| Fabric content (Cotton, Cotton/PE, PE) | -18.142 | 0.730 | -19.577, -16.708 |
| Fabric construction (Plain weave/Twill weave) | -1.164 | 1.274 | -3.669, 1.341 |
| Pesticide (Chlorpyrifos/Cypermethrin/Glyphosate/Paraquat) | -0.863 | 0.424 | -1.697, -0.029 |
| Fabric weight | -0.159 | 0.016 | -0.190, -0.128 |
| Fabric thickness | 7.904 | 4.920 | 17.770, 17.579 |

SE = standard error; 95%CI = 95% confidence interval; PE = polyester; * P < 0.05; ** P < 0.01

± SE = -0.863 ± 0.424, 95%CI = -1.697, -0.029), and fabric weight (± SE = -0.159 ± 0.016, 95%CI = -0.190, -0.128) (Table 3).

3.2 Part 2: Effectiveness of natural resin-coated fabrics in protection against exposure to pesticides

Levels of pesticide penetration through nine resin-coated fabrics are presented in Figure 4. The penetration levels were in the range from 5.3% to 9.6% for chlorpyrifos, 5–10.1% for cypermethrin, 10.8–76.8% for paraquat, and 6.1–81.8% for glyphosate. The lowest % of penetration in resin-coated fabrics for all pesticides was found in fabric C1-R (5.3% for chlorpyrifos, 5.0% for cypermethrin, 10.8% for paraquat, and 6.1% for glyphosate). When comparing the penetration levels between un-coated and resin-coated fabrics, the penetration levels of chlorpyrifos and cypermethrin in all resin-coated fabrics were significantly lower than those for un-coated fabrics (P < 0.01). The lower levels of penetration for paraquat were only found in fabric C1-R (P < 0.01), but the penetration levels in fabrics C4-R, C5-R, and CP2-R were significantly higher than those for un-coated fabrics (P < 0.01). The greatest significance of the lower levels of penetration for glyphosate was found in fabrics C1-R (P < 0.01), C2-R (P < 0.05), C5-R (P < 0.05), C7-R (P < 0.01), and CP1-R (P < 0.05). However, the penetration levels for glyphosate in fabrics C4-R and CP2-R were significantly higher than those for un-coated fabrics (P < 0.01 and P < 0.05, respectively).
4. Discussion
The study in Part 1 indicated that fabric C1, classified as 100% cotton and had the heaviest weight, ensured the lowest % of penetration for all pesticides tested at a statistical significance level of 0.05 when compared with other fabrics. Cotton fabric is widely used in daily life because it is breathable and has a hydrophilic woven structure. It has numerous pores in a woven structure, which lead to it being breathable and comfortable. Furthermore, cotton fabric can absorb liquids such as sweat at a level greater than 30%, whereas synthetic fibers can absorb less than 7% (Gohl & Vilensky, 1993). Due to the absorbance of the cotton fabric and its ability to retain large amounts of water, wearers feel more comfortable.

The multiple linear regression analysis indicated that the factors associated with pesticide penetration were fabric content, chemical type, and fabric weight. It seems that the fabrics made of 100% cotton which had more weight also had a greater potential to protect against pesticides from spraying and other types of handling. These results are in agreement with previous studies that investigated pesticide penetration through woven clothing fabrics (Lee & Obendorf, 2005; Zhang & Raheel, 2003). These other studies found that fabric thickness was one of the most highly influential factors affecting liquid penetration through woven fabrics. They also found that a thickness of fabric above 0.8 mm has the highest level of effectiveness in providing protection against pesticides. In addition, a study by Shaw and Schifflbein (2016b) also stated that fabric weight and repellent finish affected percentage penetration more than test chemicals. Our results therefore suggest that the fabrics made of 100% cotton and have greater weight serve as the first choice for protective clothing when spraying pesticides and related tasks on the farm. Nevertheless, other factors affecting pesticide penetration should be considered. A study by Aprea et al. (2004) mentioned that urinary alkylphosphate metabolites are sensitive biologic indicators of exposure to organophosphates, and the metabolite levels were influenced by type of uses of personal protection. They also mentioned that environmental conditions in farm were influenced on pesticide penetration through skin. They found that different in cultivation tunnels had differences in total skin contamination and urinary alkylphosphate metabolite levels (Aprea et al., 2005).
It has been accepted that non-woven materials generally give higher levels of prevention of pesticide penetration than most woven materials. However, these materials have low air permeability and agricultural workers may experience physical and physiological discomfort. Thermal discomfort and heat stress are the main reasons why many workers choose not to wear protective clothing (Macfarlane et al., 2013; Watson et al., 2019). Several manufactures have tried to produce protective clothing which improves comfort in terms of thermal physiology. These include water-oil repellent non-woven fabric based Sontara® and Gore-Tex® with Poly Tetra Fluoro Ethylene (PTFE) (R.H. Kim et al., 2015). However, this type of commercial protective clothing is quite expensive and generally designed to be disposable. This is an important factor behind the reason that poor agricultural workers do not access and comply with personal protective equipment (PPE) requirement (Andrade-Rivas & Rother, 2015; Garrigou et al., 2020; Jallow et al., 2017). Previous studies have evaluated the effectiveness of cotton fabrics coated with substances which have various superhydrophobic properties. Fluorocarbon finished fabric was found to be an excellent barrier finish against pesticides, but this fabric is quite expensive for poor workers in low and middle-income countries (Das et al., 2016). Natural resin-coated fabric may be an option in the protection against pesticides as it is cheap and also non-environmentally toxic. In the study in Part 2, the protection levels against chlorpyrifos and cypermethrin in all resin-coated fabrics were significantly higher than those in un-coated fabrics. Importantly, fabric C1-R had the highest efficacy in protecting against these pesticides (Penetration levels = 5.3% for chlorpyrifos and 5% for cypermethrin). In the case of herbicides, which included paraquat and glyphosate in this study, fabric C1-R also gave the highest level of protection (Penetration levels = 10.8% for paraquat and 6.1% for glyphosate), but the protective levels of other coated fabrics were unclear. It is likely that the resin-coated fabrics had the higher effectiveness to protect against insecticides (chlorpyrifos and cypermethrin) than herbicides (paraquat and glyphosate). This may be due to their water resistance and high contact angle properties. The resin-coated fabric displayed water resistance for longer than 24 hours and at a contact angle of water repellency greater than 120°. If the contact angle is higher than 90°, the fabric is considered to have hydrophobic properties (Förch et al., 2009). Another possibility is that fabric C1-R had the most weight when compared with other fabrics. Fabric weight had an effect on penetration level of pesticides through fabrics (Shaw & Schiffliebein, 2016b). Therefore, it can be concluded that fabric C1-R is the one most likely be suitable for conferring protection against all these pesticides during spraying and other associated handling activities. It has been known that PPE use can reduce pesticide exposure, but agricultural workers compliance with PPE use is likely to be poor due to several factors (Macfarlane et al., 2013). Garrigou et al. (2020) stated that thermal discomfort is one of the most highly influential factor affecting wearing of PPE failure. Watson et al. (2019) also suggested that the design of personal protective clothing should be considered both high protection and comfort. However, fabric C1-R is the heaviest when compared with other fabrics, possibly resulting in discomfort while working. Our results therefore suggest that fabric C1-R is possibly suitable for tailoring trousers rather than shirts. Another concern is that this study was conducted in only chlorpyrifos, cypermethrin, paraquat, and glyphosate. These four pesticides are widely used in agriculture, especially in Southeast Asia (Gupta, 2012; Sapbamrer, 2018; Tawatsin et al., 2015). However, agricultural workers may apply several products of pesticides. It is unpractical if agricultural workers don’t apply the specific pesticides. Therefore, further study should be conducted with the surrogate test chemical of pesticide with the highest penetration used for EN/ISO 27,065 (Shaw et al., 2018).

Some limitations have to be taken into account in the interpretation of the results. Firstly, the tests in this study involved only first time used fabrics. Further studies should be conducted to test the penetration levels after the washable fabrics or garments have been washed 30 times to achieve ISO 27,065 standard. Secondly, this study was conducted in only chlorpyrifos, cypermethrin, paraquat, and glyphosate. The tests should be conducted with the dye surrogate used for EN/ISO 27,065 (Shaw et al., 2018). Lastly, this study was conducted in a laboratory which could result in over- or under-estimation of the effects in the field. Conditions in the field would differ in several ways. Several factors in field conditions associated with exposure to pesticides included farmer factors (i.e.
movement of the workers, and job performance), farming factors (i.e. types of plantations, farm characteristics, and methods of pesticides spraying), and environmental factors (temperature and humidity). Therefore, field work now needs to be carried out to give weight to the findings of this study.

5. Conclusion
An integrative knowledge from this study suggests that a suitable fabric to protect agricultural workers from pesticide exposure is a fabric which made of 100% cotton and has greater weight.

With regard to natural resin-coated fabrics, all of the natural resin-coated fabrics (9 fabrics) had the potential to protect against chlorpyrifos and cypermethrin, whereas only one fabric (fabric C1-R) for paraquat and three fabrics (fabric C1-R, C2-R and C7-R) for glyphosate. It can be concluded that the resin-coated fabrics had the higher effectiveness to protect against insecticides (chlorpyrifos and cypermethrin) than herbicides (paraquat and glyphosate). Interestingly, fabric C1-R showed the highest levels of effectiveness in protecting against pesticides (protective level of 95% for chlorpyrifos and 95% for cypermethrin, 89% for paraquat, and 94% for glyphosate). Our results therefore suggest that fabric C1 with and without natural resin finish have the potential to protect against all these pesticides during spraying and other handling scenarios. However, fabric C1 with and without the finish was the heaviest fabric when compared with other fabrics. It might cause the wearers uncomfortable while working in farms. Therefore, this fabric is possibly suitable for tailoring trousers rather than shirts. These findings are relevant to advise agricultural workers to choose a suitable fabric for protecting themselves from pesticide exposure. Nevertheless, this study is a preliminary study, and it should not be used as a basis for recommendation of PPE. Further research is therefore needed to assess the efficacy of pesticide protection of natural resin-coated fabrics by conducting with EN/ISO 27,065, testing in simulated and field conditions, and testing after multiple washes.

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All of the authors declare that they have no competing interests.

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