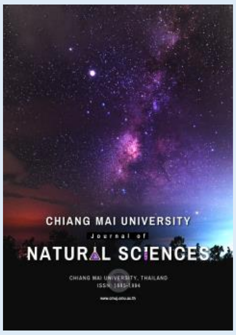

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Research article

Relationship of Respirable Dust Exposure to Pulmonary Function among Informal-sector Weavers using Indigo-dyed Cotton

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Abstract Informal-sector weavers using indigo-dyed cotton are occupationally exposed to respirable dust which may contain contaminants from chemicals used for pH adjustment in the natural indigo fermentation process. The major health problems associated with respirable dust induce pulmonary function impairment and respiratory disease. However, there have been few studies into the respiratory problems of informal-sector weavers in Thailand. This study investigated the link between occupational respirable dust exposure and pulmonary function among weavers using indigo-dyed cotton in Thailand. A cross-sectional study was conducted of 147 weavers located in Sakon Nakhon province. Respiratory dust (RD) samples were collected from the immediate breathing zone of all weavers. Lung function was measured using a portable spirometer operated by a trained physician and the spirometric results were examined by a pulmonologist before reporting. Most participants were female (98.6%) and the median reported interquartile age (IQR) was 58 (50–62.75) years. Average predicted values for FVC, FEV1 and FEV1/FVC were 92.9% (±20.7), 96.7% (±17.9) and 88.3% (±10.8). Of the respiratory function patterns of the 147 weavers, 20 (13.6%) were restrictive, 11 (7.5%) were obstructive and 1 (0.7%) was combined. The average RD concentration (mean ± SD) was 47.9 ± 28.3 $\mu g/m^3$. Multivariate linear regression models showed an increase of 1 $\mu g/m^3$ in RD exposure was associated with a 0.179% lower level of FEV1 (95% confidence interval (CI) -0.278 to -0.080) and a 0.068 % lower level of FEV1/FVC (95% CI -0.128 to -0.008). Our findings suggested that exposure to respirable dust might impair pulmonary function in informal-sector cotton weavers.

Keywords: Indigo-dyed Cotton, Informal-sector Weavers, Occupational Exposure, Pulmonary function, Respirable Dust

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INTRODUCTION

Indigo-dyed cotton made by impregnating a natural dye from indigo into the fibers is considered traditional to Sakon Nakhon province since ancient times. Currently, these indigo-dyed cotton products are being promoted within Thailand and abroad. Indigo-dyed products generate the greatest income for people in Sakon Nakhon, Thailand. However, the manufacturing process also affects weaver's health.

The production process for indigo-dyed weaving involves: 1) a natural indigo fermentation process for indigo dyeing; 2) indigo dyeing of fibers; 3) spinning; and 4) indigo-dyed fabric weaving. All of these processes can produce pollution in the work environment due to the inhalation of respiratory dust, especially during spinning and weaving (Rajsri, 2013; Ali, 2018). The respiratory dust from indigo-dyed weaving may contaminants of organic dust generated during the natural indigo fermentation process such as ash and calcium hydroxide used for pH adjustment (Purnama, Hidayati, Safitri, & Rahmawati, 2017; Son, 2019) and microorganism contaminants (Phakthongsuk, Sangsupawanich, Musigsan, & Thammakumpee, 2007; Aino et al., 2018) which may cause respiratory disorders associated with lung function resulting from the accumulation of respiratory dust in the respiratory tract (Paulin & Hansel, 2016; Xing et al., 2016). Occupational exposure to different types of dust is a major contributor to respiratory disease (Kumar et al., 2008; Holm & Festa, 2019) especially respiratory dust exposure which may occur indoors and outdoors (Kumar et al., 2008; Ingale et al., 2011). Previous study reported on respiratory dust emission from cotton fibers in textile factories (Juliana J. et al., 2003). In particular, a study in India reported that pollution from textile-dyeing factories involved concentrations of particulate matters (PM2.5 and PM10) which had significantly positive relationships with respiratory symptoms and chronic obstructive pulmonary disease during the careers of workers (Hinson et al., 2016; Dangi & Bhise, 2017; Gupta, Biswas, & Agrawal, 2017). Studies among home-based garment workers in Thailand also found that exposure to garment dust was significantly correlated with respiratory symptoms (Chumchai Pornlert et al., 2014). Additionally, cotton dust exposure has been linked to decreased pulmonary function and increased cancer risk (McElvenny et al., 2011; Paulin & Hansel, 2016; Ali et al., 2018; Ben Khedher et al., 2018). Furthermore, long-term exposure to textile dust has been associated with chronic obstructive pulmonary disease (Lai & Christiani, 2013). These diseases are termed occupational hazards (Wang & Zhao, 1987).

Occupational exposure to respirable dust induces pulmonary function impairment and respiratory health problems and thus, informal-sector weavers using indigo-dyed cotton are at risk of exposure to respirable dust which may contain contaminants of chemicals used for pH adjustment in the natural indigo-dyed fermentation process. Despite the growing concern associated with occupational exposure, there have been few studies into the respiratory problems of informal-sector weavers in Thailand. Consequently, the current study aimed to determine a link between occupational respirable dust exposure and pulmonary function among weavers using indigo-dyed cotton in Thailand.

MATERIALS AND METHODS

Study design and participants

A cross-sectional study was conducted among 147 weavers using indigo-dyed cotton in 3 of 18 districts in Sakon Nakhon province, Thailand, because the majority occupation in the region is indigo-dyed cotton weaving. The sample size was calculated using the infinite population proportion formula (Enderlein, 1995) because it was not feasible to estimate the total number of informal-sector weavers using indigo-dyed cotton in Sakon Nakhon province. All 147 weavers in the sample were located in the 3 sampled districts. The eligible criteria for participants were adults aged over 30 years who spent their time weaving for 8 hours per day, with at least 2 years' experience and had no history of smoking. Based upon convenience sampling, in each household, one weaver meeting these inclusion criteria was invited to participate in the study. From

August to December 2019, trained health volunteers conducted face-to-face interviews using a questionnaire that covered the demographic status and also the characteristics of indigo weaving. Underlying diseases, weight and height were assessed based on self-reporting during the interview. The study protocol was approved by the Sakon Nakhon Public Health Office Ethics Committee for Humans Research (COA No. SKN REC 2019-020). All participants read and signed the consent form before enrollment.

Exposure assessment

Respiratory dust exposure samples were collected once at a weaving operation station for each participant during a working session of 8 hours following the guidelines for persons employed in cotton dust environments (Occupational Safety and Health Administration, 2007). Briefly, a personal air sampling pump (SKC224-PCXR8 model; SKC Inc.; USA) connected with an aluminum cyclone (SKC model 37 mm; Cat No. 225-01-02) was calibrated before and after the sampling period. The sampling flow rate was set at 2.5 L/minute. Polyvinyl chloride filters (37 mm, 5.0 micrometer pore size) were pre- and post-weighed at controlled room conditions using an electrical microbalance. The sampling device was placed in the breathing zone of a weaver working at the weaving station (at a height of 1–1.5 meters above the floor). The RD concentration was calculated based on gravimetric analysis of the respiratory dust using air samplers with internal filtration capsules (Sean O'Connor et al., 2014).

Spirometry assessment

Pulmonary function measurements were performed using a portable spirometer (Medical International Research; Inc.; USA; WinspiroPRO software) in pre-shift of work, same day with the air sampling. Spirometry was done according to the guidelines of the Official American Thoracic Society and European Respiratory Society Technical Statement (Miller et al., 2005; Graham et al., 2019). The age, height and weight of each participant were entered in the software before performing the test. The spirometric parameters recorded were: forced vital capacity (FVC), predicted percentage of forced expiratory volume for 1 second (FEV1) and their ratio (FEV1/FVC). All spirometric measurements were taken on workers who were in the standing position without wearing a nose clip. The procedure was explained to participants who were then asked to practice until they felt comfortable with the process. Spirometric values were recorded based on three acceptable readings, with the highest rate of the three readings used for analysis. Pulmonary function measurements were conducted by a trained physician in occupational medicine and the spirometric results were examined by a pulmonologist before reporting. Spirometric explanations were based on percentage-predicted lung volumes through the spirometer and were stratified into two groups, namely the normal group (FEV1/FVC>70%, FEV1 and FVC>80% predicted) and the abnormal group consisting of obstructive (FEV1/FVC<70%, FEV1<80% predicted), restrictive (FEV1/FVC>70%, FVC<80% predicted) and combined (a combination of obstructive and restrictive patterns).

Statistical analysis

All analyses were performed using the IBM SPSS statistical software for Windows (version 22; IBM SPSS; Chicago, IL, USA). Normal-distributed continuous variables were reported as the mean ± standard deviation (SD). For skewed data, the median (interquartile range; IQR) was reported. Categorical variables were presented using the frequency (n) and percentage (%). Lung function values were calculated using the percentage predicted FEV1, FVC and the FEV1/FVC ratio. Multivariate linear regression was used to predict the relationship between the RD exposure and pulmonary function of the weavers using indigo-dyed cotton. Adjustment for covariate factors was based on the recommended factor effect for lung function that included age, body mass index (BMI), work experience, allergic rhinitis and asthma history. For respirable dust, the association was reported for a 1 $\mu g/m^3$ increase in the average RD concentration. A *P*-value less than 0.05 was defined as statistically significant.

RESULTS

Table 1 shows the general characteristics for the weavers using indigo-dyed cotton. Most of the participants were female (98.6%) and the median IQR was 58 (50–62.75) years old. The mean height, weight and BMI of the indigo weavers were 153.4 ± 5.9 cm, 57.2 ± 10.5 kg and 24.3 ± 4.3 kg/m^3, respectively. Average work experience (±SD) was 8.5 (±7.5) years and average workdays (±SD) were 5.0 (±1.43) days per week. Of the 147 weavers, 55.8% worked with natural indigo-dyed cotton and 44.2% worked using natural and chemical weaving of indigo-dyed cotton. Of the sample, 26.5% had an underlying disease and 10.2% had a history of allergic rhinitis and asthma. Most participants had cotton dust exposure history (76.2%).

Table 1. General characteristics of indigo-dyed cotton weavers.

Characteristic	Total (n=147)
Age, (years) median (IQR) (max=83 and min=30)	58 (50–62.75)
Gender, n (%)	
Male	2 (1.4)
Female	145 (98.6)
Height (cm), mean ± SD (max=175 cm. and min=135 cm.)	153.4 ± 5.9
Weight (kg.), mean ± SD (max=113 kg. and min=40 kg.)	57.2 ± 10.5
Body Mass Index (kg/m^3), mean ± SD (max=171.9 kg/m^3 and min=17.8 kg/m^3)	24.3 ± 4.3
Educational status, n (%)	
Primary school and under	122 (83.0)
High school and above	25 (17.0)
Marital status, n (%)	
Single	19 (13.9)
Married	128 (87.1)
Type of indigo-dyed fabric, n (%)	
Natural dyed	82 (55.8)
Mixed dyed	65 (44.2)
Work experience (years), mean (± SD)	8.5 (±7.5)
Workdays per week (days), mean (±SD)	5.0 (±1.43)
Underlying disease, n (%)	
No	108 (73.5)
Yes	39 (26.5)
Allergic rhinitis and asthma history, n (%)	
No	135 (89.8)
Yes	15 (10.2)
*Cotton dust exposure history, n (%)	
No	35 (23.8)
Yes	112 (76.2)

*History of cotton dust exposure in the past.

The mean (±SD) percentage predicted values for FVC, FEV1 and FEV1/FVC were 92.9 (±20.7), 96.7 (±17.9) and 88.3 (±10.8), respectively. Out of the 147 weavers using indigo-dyed cotton, 115 (78.2%) were in the normal group and 32 (21.8%) were in the abnormal group, with the pattern of the latter being 20 (13.6%) restrictive, 11 (7.5%) obstructive and 1 (0.7%) combined restrictive and obstructive. The average RD concentration (mean ± SD) was 47.9 ± 28.3 μg/m^3 (Table 2).

Table 2. Spirometry value, spirometry pattern and respirable dust among indigo-dyed cotton weavers (n=147)

Variable	N (%)
Spirometry value* (%, mean ± SD)	
**FVC (max=179 and min=50)	92.9 ± 20.7
***FEV1 (max=159 and min=48)	96.7 ± 17.9
FEV1/FVC (max=100 and min=34)	88.3 ± 10.8
Spirometry pattern, n (%)	
Normal group	115 (78.2)
Abnormal group	32 (21.8)
Restrictive	20 (13.6)
Obstructive	11 (7.5)
Combined	1 (0.7)
Respirable dust (μg/m^3, mean ± SD) (maximum 116.7 μg/m^3 and minimum 2.8 μg/m^3)	47.9 ± 28.3

* Spirometry value=percentage-predicted lung volumes (%).
**FVC= forced vital capacity
***FEV_1=predicted percentage of forced expiratory volume for 1 second

The multivariate linear regression models showed an association between RD exposure and lung function. The unadjusted model showed an increase of 1 μg/m^3 of RD exposure was associated with a 0.177% lower level of FEV1 (B=-0.177, 95% CI -0.277 to -0.077) and a 0.074% lower level of the FEV1/FVC ratio (B=-0.074, 95% CI -0.135 to -0.012). After adjusting the model for age, BMI, work experience and allergic rhinitis and asthma history, there was an increase of 1 μg/m3 of RD exposure associated with a 0.179% lower level of FEV1 (B=-0.179, 95% CI -0.278 to -0.080) and a 0.068% lower level of the FEV1/FVC ratio (B=-0.068, 95% CI -0.128 to -0.008). However, the predicted percentage FVC did not show any association with RD exposure (Table 3).

Table 3. Multivariate linear regression model for RD exposure and pulmonary function (spirometry) of weavers using indigo-dyed cotton (n=147).

Pulmonary function (%)	Respirable dust concentration (μg/m^3)							
	Unadjusted model				Adjusted model[a]			
	B	β	95% CI	p-value	B	β	95% CI	p-value
FCV	-0.069	-0.094	-0.188, 0.051	0.26	-0.071	-0.098	-0.193, 0.050	0.25
FEV1	-0.177	-0.279	-0.277, -0.077	<0.001**	-0.179	-0.283	-0.278, -0.080	<0.001**
FEV1/FVC	-0.074	-0.193	-0.135, -0.012	0.019*	-0.068	-0.178	-0.128, -0.008	0.027*

[a]Adjusted for factors associated with pulmonary function in adults using age, BMI, work experience and allergic rhinitis and asthma history.
* *P* <0.05, ** *P* <0.001.

DISCUSSION

The key findings of this study were the association between exposure to RD from indigo-dyed weaving and pulmonary function impairment among weavers using indigo-dyed fabric. Specifically, 115 (78.2%) were in the normal group (higher level of lung function) and 32 (21.8%) were in the abnormal group (lower level of lung function value; patterns of obstructive, restrictive and combined). The average RD concentration was significantly higher among those who had pulmonary function abnormality which was consistent with our significant finding that an increment of 1 μg/m^3 of RD resulted in a significant decline in FEV1 and FEV1/FVC. Similarly, in Pakistan, a study involving 303 adult male textile workers from the spinning and weaving sections of five mills reported a relationship between increased cotton dust exposure with reductions in the mean FEV1 and FEV1/FVC(Ali et al., 2018). Cotton dust exposure can affect respiratory problems and symptoms, as was reported by Jadhav A. J. et al. (2016) who found that the reduction in FEV1/FVC was significant in the exposed group of cotton textile workers in the spinning mill developing respiratory problems reflected by reduced pulmonary function. In addition, the study of Silpasuwan P. et al. (2016) showed that there was a significant association between respiratory tract signs and symptoms and lung function capacity (OR = 52.15, 95% CI = 6.49, 419.60) among home-based garment workers in Thailand (Silpasuwan et al., 2016). A long-term study of respiratory health effects in textile workers also found exposure to cotton dust led to increased lung disease (Lai & Christiani, 2013). However, our results did not find any association between RD exposure and FVC in the adjusted model, which was consistent with other studies that found no association between cotton dust exposure and FVC (Omid Aminian et al., 2013; Ali et al., 2018). The value of FVC is primarily an indicator of a restrictive pattern which may not be a significant indicator compared to FEV1, which indicates the obstruction pattern. However, it was more prevalent and severe among weavers. The current study controlled potential confounding factors in relation to lung function indices, with other lung function risk factors being age, BMI and work experience that also impact on lung function (Jaen et al., 2006; Ali et al., 2018); in addition, weavers who smoked were excluded.

All participants were also monitored for individual respiratory dust exposure using a personal air pump, with the mean RD exposure among the indigo weavers being 47.9 ± 28.3 μg/m^3, which was lower than the study in Perak, Malaysia, where the mean cotton dust exposure among textile mills workers was 95.43 ± 45.78 μg/m^3 (Juliana J., 2003) and lower than in a study in Thailand that reported the respiratory dust concentration among cotton-fabric sewing workers was 0.52 ± 0.06 mg/m^3 (Phakthongsuk et al., 2007) . A possible reason supporting this finding may be the differences in the setting area, workplace conditions and section activity that were reflected in different levels of cotton dust exposure. In addition, the chemical residues for pH adjustment from the indigo-dyed fermentation process such as ash, calcium hydroxide and micro-organic contaminants (Phakthongsuk et al., 2007; Aino et al., 2010) can potentially contaminate cotton dust and may result in lung function and respiratory problems. Furthermore, the work duration of the informal weavers was more than 8 hours a day and they worked for 5 days a week (40-hour work week); thus, it is possible that the exposure could increase the risk of abnormal pulmonary function in the current study. However, it did not exceed the standard established permissible exposure limits for cotton dust exposure during an 8 hour work shift (750 μg/m^3 of respirable dust of weaving area) (Occupational Safety and Health Administration, 2007).

The current study has been one of the few to date to examine the association between pulmonary function and respirable dust exposure of weavers using indigo-dyed cotton in Thailand. Our study considered area monitoring of RD exposure during an eight-hour work shift based on objective assessment, resulting in better evaluation of personal respirable dust exposure. Moreover, all spirometric methods were assessed and reviewed by a specialist and a pulmonologist to ensure quality measurement procedures. Therefore, our current findings should be generalizable to similar handmade cotton-weaving operations in Thailand and other developing countries.

Some potential limitations might have affected our results. First, this was a cross-sectional study and did not account for weavers who became ill during their work; consequently, weavers were only studied who at the time were able to work. Thus, we could only provide evidence for a possible association and not for causation, so further studies are needed. Second, the study included weavers who had work experience for at least 2 years, whereas respiratory illnesses may take longer to develop. Finally, the sample size was small; however, despite this limitation, we were still able to predict an important relationship between respirable dust exposure and pulmonary function.

CONCLUSION

This study provided evidence that respirable dust exposure was associated with a decrease in pulmonary function among weavers working in the informal sector and using indigo-dyed cotton. Our findings revealed new information for occupational health in the informal sector indigo-dyed cotton at home. Public health officials in the community should encourage safe and healthy workplaces by educating home-based workers on the use of personal protective equipment in the weaving workplace. Improving the working conditions at home and minimizing cotton dust exposure among indigo-dyed cotton weavers are recommended actions.

AUTHOR CONTRIBUTIONS

Ratanee Kammoolkon assisted in data collection, data analysis, statistical analysis and wrote the manuscript. Assistant Prof. Dr. Nutta Taneepanichskul assigned concepts and design of the study and approved the manuscript. Professor Surasuk Taneepanichskul was a mentor throughout this study. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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