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Airborne concentrations of bacteria and fungi in Thailand border market

Pradub Reanprayoon · Wattanachai Yoonaiwong

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Abstract Thailand border market is where the local Thais, Cambodians, Laotians, and Burmeses exchange their goods and culture at the border checkpoints. It is considered to be the source of aerial disease transmission especially for foreigners because it is always very crowded with people from all walks of life. Unhealthy air quality makes this area high risk of spread of airborne diseases. This study assessed airborne concentrations of bacteria and fungi in a border market to improve exposure estimates and develop efficient control strategies to reduce health risk. The density and distribution of airborne bacteria and fungi were investigated in the Chong Chom border market in Surin Province, Thailand. Eighteen air sampling sites were taken from outdoors and various work environments including indoor footpaths, wooden handicraft shops, electronic shops, the secondhand clothing shops, and fruit market areas. Exposed Petri plate method and liquid impinger sampler were used for sampling at the breathing zone, 1.5 m above the floor level, during weekend and holiday. Meteorological factors such as relative humidity, temperature, and light intensity were collected by portable data logger. The relative humidity was 67–73%, and temperature 29–33°C, and light varied between 18 and 270 Lux m^{-2}. Gram-positive and Gram-negative bacteria were found at a mean value of 10^4 CFU m^{-3}, and airborne fungi of 10^3 CFU m^{-3} were recorded. The highest concentration of culturable airborne microorganisms was found along the indoor footpath (9.62×10^4 CFU m^{-3} and 750.00 CFU/plate/h for impingement and sedimentation methods, respectively), the fruit market area (7.86×10^4 CFU m^{-3} and 592.42 CFU/plate/h for impingement and sedimentation methods, respectively), and the secondhand clothing shop (4.59×10^3 CFU m^{-3} and 335.42 CFU/plate/h for impingement and sedimentation methods, respectively) for Gram-positive bacteria, Gram-negative bacteria, and fungi, respectively. The lowest concentration of Gram-positive bacteria, Gram-negative bacteria, and fungi was found only at the outdoor area at 1.53×10^4 CFU m^{-3}, 0.93×10^4 CFU m^{-3} and 0.80×10^3 CFU m^{-3} by means of impingement method and 136.67 CFU/plate/h, 69.25 CFU/plate/h, and 62.00 CFU/plate/h by means of sedimentation methods for Gram-positive bacteria, Gram-negative bacteria, and fungi, respectively. The most frequently present airborne bacteria were identified as *Bacillus*, *Corynebacteria*, *Diplococcus*, *Micrococcus*, *Acinetobacter*, *Alcaligenes*, *Enterobacter,* and spore former rods. *Acremonium*, *Aspergillus*, *Cladosporium*, *Penicillium,* and *Sporotrichum* were the most frequently found aerosol fungi genera. The distribution of airborne microorganisms correlated with relative

P. Reanprayoon (✉) · W. Yoonaiwong
Department of Agriculture and Environment, Faculty of Science and Technology, Surindra Rajabhat University, Surin Province 32000, Thailand
e-mail: reanprayoon@yahoo.com; reanprayoon@hotmail.com

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humidity and light factors based on principal component analysis. In conclusion, the border market is a potential source of aerial disease transmission and a various hazards of bioaerosols for workers, consumers, sellers, and tourists. The bioaerosol concentration exceeded the standard of occupational exposure limit. Many major indicators of allergenic and toxigenic airborne bacteria and fungi, *Acinetobacter*, *Enterobacter*, *Pseudomonas*, *Cladosporium*, *Alternaria*, *Aspergillus,* and *Penicillium*, were found in the various market environments.

Keywords Border market environment · Airborne · Bacteria · Fungi · Indoor air · Outdoor air · Bioaerosols · Principal component analysis (PCA)

1 Introduction

Airborne microorganisms are considered as a key factor and as an indicator of the level of air pollution. Microorganisms, particularly airborne fungi and bacteria, have been shown to be a health risk and can cause diseases such as pneumonia, asthma, rhinitis (e.g., cold, hay fever), respiratory infection (Garrett et al. 1997; Grinn-Gofroń and Mika 2008), and sick building syndrome (Gonçalves et al. 2010; Kasprzyk and Worek 2006; Li and LaMondia 2010). Only complete airborne microorganisms can be infectious whereas toxic and allergic reactions can be caused by microorganism fragments or byproducts, such as mycotoxins, endotoxin (Anttila 2000; Kristian 2003; Fabian et al. 2005). More than 80 genera of fungi have been linked with symptoms of respiratory tract allergies (El-Morsy 2006; Kurup 2003). Indoor airborne microfungi are capable of producing a variety of mycotoxins and other biologically active metabolites such as carcinogenic mycotoxins, aflatoxin B1, austocystins, and sterigmatocystins, which also act as a strong inhibitor of tracheal ciliary movement (Piecková and Jesenská 1998; Fabian et al. 2005). For example, *Chaetomium globosum* produces cytotoxic chaetomins and chaetoglobosins that inhibit cell division and glucose transport. *Penicillium polonicum* can produce three types of highly toxic compounds; tremorgenic verrucosidins, cytotoxic penicillic acid, and nephrotoxic glycopeptides. Anttila (2000) reported that fungi and mycotoxins released from fungal spores and colony fragments induced acute intoxication and had many adverse effects such as carcinogenic, mutagenic, teratogenic, hormonal, hemorrhagic, immunotoxic, nephrotoxic, hepatotoxic, dermatoxic, neurotoxic, antibiotic, hematological changes, releasers of interleukins, and lipid peroxidation.

Gram-negative bacteria are considered to be a major group of airborne pathogens because they are producers of endotoxins, which have a wide range of health effects. Endotoxins are macromolecules and are comprised in the outer membrane of the cell wall of Gram-negative bacteria. Endotoxins consist of proteins, lipids, and lipopolysaccharides (LPS). Inhalation of bacterial endotoxin or its chemically pure form called lipopolysaccharide (LPS) has been associated with acute and chronic inflammation and lung function decrements (Heine et al. 2001; Morgenstern et al. 2005; Nilsson et al. 2011).

Many studies have shown that the concentration of fungal spores in indoor and outdoor air is strongly related to meteorological factors such as temperature, relative humidity, and duration of daylight, agents of air pollution (Kakde et al. 2001; Sen and Asan 2009; Zhao and Wu 2009) and areas and seasons (Aríngoli et al. 2008; Schlesinger et al. 2006). These bioaerosols can also be widely distributed over hundreds of kilometers, even at intercontinental scales (Griffin et al. 2007; Prospero et al. 2005).

The Chong Chom border market is a trade, culture, and tourist centre at the border checkpoint for local Thais and Cambodians. It has a tropical climate, with the annual temperature at 32°C and humidity averaged at 65%, which is optimal condition for the growth of bioaerosols. The market is crowded with workers, customers, sellers, tourists, especially foreign visitors in weekend and holidays. It renders a favorable environment for the proliferation of microorganisms and the incidental elevation of airborne microorganisms and is also considered as a source of aerial disease transmission. Study on airborne concentrations of bacteria and fungi is important in improving exposure estimates and developing efficient control strategies to reduce health risk. The present study evaluated the concentrations of airborne microorganisms; especially bacteria and fungi, at various environments in the Chong Chom border market, Thailand, during weekend and holidays.

2 Materials and methods

2.1 Meteorological and aerobiological sampling

Air samples were collected from outdoor and the five work environments, which are indoor footpath, wooden handicraft shop, electronic shop, the second-hand clothing shop, and fruit market areas. Three samples per environment were taken twice a day for this investigation. Sampling was conducted during April–May 2010 during weekend and holidays between 11 am and 2 pm. Meteorological data for relative humidity and temperature were collected by means of data logger (GRAPHTEC midi LOGGER GL800), and light was measured with a digital light meter (model TES-1335) during each airborne sampling event.

A sedimentation, an open plate technique, and liquid impingement methods (Awad et al. 2010; Griffin et al. 2010; Yang and Heinsohn 2007) were employed for qualitative and quantitative isolation of airborne fungi and bacteria. Each sampling times, 324 petri plates (18 for each sample, 6 for each medium) containing Blood, MacConkey, and Sabouraud Dextrose agar (Difco) were used to obtain Gram-positive bacteria, Gram-negative bacteria, and microfungi, respectively. Petri plates were exposed to air for 15 min for sedimentation method. Three Petri plates (90 mm diameter) of each medium were used in each sample. The samples were taken at the height of 1.5 m above the ground level. For impingement method, a liquid impinger containing 20 mL phosphate buffer (KH_2PO_4 0.4%, K_2HPO_4 1.36%) was operated at a flow rate of 12.5 L min^{-1} for 15 min. The microbial suspension was diluted in a tenfold series, and 0.1-mL aliquots were spread-plated onto the surface of triplicate plates of the above-mentioned media. All culture plates were incubated at 25°C for 2–7 days then microorganism were counted and analyzed (Awad et al. 2010; Griffin et al. 2010).

2.2 Microbiological analysis

Total bacterial and fungal microorganisms were counted and reported as colony-forming units per cubic meter of air (CFU m^{-3}) for impingement methods (Lin et al. 1999; Stryjakowska-Sekulska et al. 2007). For sedimentation method, microorganisms were calculated as total CFUs per plate per hour (CFU/plate/h) (Di Giulio et al. 2010). Viable bacteria and fungi from the impingement method were used mainly to analyze the concentrations of microbial indicators at each environment because of many advantages: known volume of air is analyzed, suitable for high concentration of microorganisms in the atmosphere and for the assessment of viable airborne microorganisms, avoided desiccation of solid surfaces and impaction of particles onto agar surfaces (Cabral 2010). Bacterial isolates were identified by using Gram stain, growth on MacConkey and triple sugar iron agar, oxidase test, oxidation–fermentation, catalase test, and IMVic reactions (Van Houdt et al. 2009). Fungal colonies were identified to the genus and species level by using macroscopic and microscopic features (Barnett and Hunter 1999).

2.3 Statistical analysis

Correlation analyses were performed to determine the relationship between meteorological factors and airborne microorganisms isolated from different sites. Analysis of variance (ANOVA) was used to estimate the significant difference in microorganism populations, concentrations, and environmental parameters among different locations at the border market. In addition, a multivariate statistical methodology was used for characterizing distribution patterns of Gram-positive bacteria, Gram-negative bacteria, and fungi at different locations, based on principal component analysis (PCA). PCA can be used as an explorative tool, visualizing the correlations between samples, between variables, and between samples and variables. In the so-called biplots, relationships between samples on one side and between variables on the other side are easily observed, as well as relations between samples and variables. Focusing on samples, closely related samples will plot close to one another, and groups of related samples appear as clusters. Closely correlated variables will plot at small distances from each other, and at sharp angles with respect to the origin. Variables that plot at opposite sides of the origin, on the other hand, are negatively correlated. Finally, variables that are important for certain samples will point toward them (Vervaet et al. 2002; Primpas et al. 2010; Jaumot and Gargallo 2010).

3 Results

The measurement results of metrological factors such as temperature, light intensity, and relative humidity were summarized in Table 1. Temperature and relative humidity were relatively higher at indoor locations compared with outdoor area. For relative humidity, the highest level was recorded at the secondhand clothing shop (73.50%). Temperature peaked at the wooden handicraft shop (33.38°C) and lowest along indoor footpath area. The highest concentration of light (270.00 Lux m^{-2}) was detected in outdoor area and followed by indoor footpath (190.00 Lux m^{-2}) and fruit market area (180.00 Lux m^{-2}) as shown in Table 1. ANOVA indicated that there was no statistically significant difference in temperature and relative humidity among various locations. Significant differences ($P < 0.001$) were observed in the amount of light (Table 1). An LSD test of these 6 locations found that there was not significantly different only between electronic shop and secondhand clothing shop ($P = 0.202$).

The concentrations of airborne bacteria at the Chong Chom border market varied at different sites from 1.53 to 9.62 $\times$ 10^4 and from 0.93 to 7.86 $\times$ 10^4 CFU m^{-3} for Gram-positive and Gram-negative bacteria, respectively. For viable fungi, the concentration showed at 0.80–4.59 $\times$ 10^3 CFU m^{-3} (Table 2). Based on sedimentation method, airborne microorganisms ranged between 136.67 and 675.39 CFU/plate/h, 0.93–7.86 CFU/plate/h, and 62.00–335.42 CFU/plate/h for Gram-positive, Gram-negative bacteria, and airborne fungi, respectively. The highest airborne bacteria exposure was found along the indoor footpath with Gram-positive bacteria (9.62 $\times$ 10^4 CFU m^{-3}, 750.00 CFU/plate/h using impingement and sedimentation methods, respectively) while Gram-negative bacterial airborne was found in the fruit market area (7.86 $\times$ 10^4 CFU m^{-3} and 592.42 CFU/plate/h using impingement and sedimentation methods, respectively). For airborne fungi, the highest concentration was found inside the secondhand clothing shop (4.59 $\times$ 10^4 CFU m^{-3} and 335.42 CFU/plate/h using impingement and sedimentation methods, respectively). A one-way analysis of variance (ANOVA) of airborne concentrations, Gram-positive bacteria, Gram-negative bacteria, and fungi collected by sedimentation and impingement methods among six locations, resulted in a P value <0.001 (Table 2), indicating a statistically significant difference among locations in all group of aerosol microorganisms. An LSD test of airborne concentrations at six locations exhibited that airborne pathogens differed significantly ($P < 0.05$) among the five investigated environments. No significant difference ($P > 0.05$) was observed between indoor footpath and fruit market area ($P = 0.122$), between wooden handicraft and secondhand clothing shops ($P = 0.305$), and between wooden handicraft and fruit market areas ($P = 0.117$) for Gram-positive bacteria, while for Gram-negative bacteria, no significant differences were observed between outdoor and wooden handicraft shop ($P = 0.592$) and between electronic and secondhand clothing shops ($P = 0.104$). For airborne fungi, LSD test presented that no significant difference ($P > 0.05$) was found between indoor footpath area and secondhand clothing shop ($P = 0.176$) and between electronic shop

Table 1 Shows temperature (°C), light intensity (Lux/m^2), and relative humidity (%) at various locations in the Chong Chom border market

Locations	Temperature (°C)	Light (Lux/m^2)	Relative humidity (%)
Outdoor	32.50 ± 0.35	270.00 ± 2.00	67.25 ± 0.99
Indoor footpath	29.50 ± 2.00	190.00 ± 2.00	67.50 ± 1.30
Wooden handicraft shop	33.38 ± 1.41	18.00 ± 4.50	67.25 ± 1.21
Electronic shop	31.50 ± 1.32	75.00 ± 5.00	68.00 ± 1.77
Secondhand clothing shop	31.25 ± 1.56	80.00 ± 7.81	73.50 ± 5.23
Fruit market area	31.00 ± 1.41	180.00 ± 3.00	67.75 ± 1.59
F value	2.591	1273.144	2.902
P value	0.082	<0.001	0.061

All values are mean of triplicate readings (±standard deviation)

Table 2 Shows the mean concentrations of airborne microorganisms at various environments in the Chong Chom border market

Locations	Airborne microorganisms					
	Gram-positive bacteria		Gram-negative bacteria		Fungi	
	CFU/m^3 of air[a]	CFU/plate/h[b]	CFU/m^3 of air[a]	CFU/plate/h[b]	CFU/m^3 of air[a]	CFU/plate/h[b]
Outdoor	1.53×10^4	136.67	0.93×10^4	69.25	0.80×10^3	62.00
Indoor footpath	9.62×10^4	750.00	6.83×10^4	531.82	4.20×10^3	307.53
Wooden handicraft shop	8.43×10^4	647.02	1.14×10^4	82.25	1.78×10^3	124.82
Electronic shop	3.59×10^4	255.67	3.14×10^4	231.09	2.61×10^3	201.96
Secondhand clothing shop	8.05×10^4	603.22	3.81×10^4	198.98	4.59×10^3	335.42
Fruit market area	9.03×10^4	675.39	7.86×10^4	592.42	2.55×10^3	193.67
F value	175.261	323.579	113.542	232.998	56.162	90.572
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

All values are mean of triplicate readings (mean values)

[a] Collected by impingement method

[b] Collected by sedimentation method

Table 3 Proportions of airborne microorganism at various environments in the Chong Chom border market

Airborne microorganisms	Outdoor	Indoor footpath	Wooden handicraft shop	Electronic shop	Secondhand clothing shop	Fruit market area
Gram-positive bacteria	60.23	57.02	86.47	51.36	65.35	52.67
Gram-negative bacteria	36.61	40.49	11.69	44.93	30.93	45.84
Fungi	3.15	2.49	1.83	3.70	3.72	1.49

and fruit market area ($P = 0.827$). On the sedimentation plates, no significant differences were found between wooden handicraft shop and fruit market area ($P = 0.177$) for Gram-positive bacteria and between outdoor and wooden handicraft shop ($P = 0.538$) for Gram-negative bacteria. For airborne fungi, LSD test indicated no significant difference ($P > 0.05$) with impingement method between indoor footpath area and secondhand clothing shop ($P = 0.098$) and between electronic shop and fruit market area ($P = 0.603$). In addition, the proportion of airborne microorganism showed Gram-positive bacteria > Gram-negative bacteria > fungi in all sampling sites (Table 3). The predominant bacteria genera found at each location in the Chong Chom border market area was shown in Table 4. Gram-positive bacteria *Bacillus*, *Corynebacteria*, *Diplococcus*, *Micrococcus,* and spore former rods were predominant at all sampling sites. Particularly, *Bacillus* was the major component of aerosol bacteria at outdoor (19.51%), indoor footpath (19.33%), the wooden handicraft shop (33.23%), and the secondhand clothing shop (17.20%), whereas *Pseudomonas* were the major dominant bacteria only in the electronic shop (20.51%) and fruit marker area (17.05%) as shown in Table 4. *Acinetobacter*, *Alcaligenes,* and *Enterobacter* were prevalent in all locations for Gram-negative bacteria. In the electronic shop, the fruit market area, and indoor footpath, Gram-negative airborne bacteria were frequently isolated 46.66, 46.54, and 41.52%, respectively.

A total of 330 airborne fungal isolates belonging to 12 fungal genera were identified (Table 5 and Fig. 1). *Aspergillus* was the dominant genera in the wooden handicraft shop (42.13%), the secondhand clothing shop (33.77%), indoor footpath (27.38%), and the fruit market area (17.65%), whereas *Penicillium* and *Alternaria* were the highest fungal aerosol concentrations observed in the electronic shop (62.74%) and the outdoor (31.25%), respectively. Among 6

Table 4 Percentages of airborne Gram-positive and Gram-negative bacteria isolated from various environments in the Chong Chom border market

Bacteria	Outdoor	Indoor footpath	Wooden handicraft shop	Electronic shop	Secondhand clothing shop	Fruit market area
Gram-positive genera						
Rods	34.15	29.91	66.77	34.17	29.34	17.41
Bacillus	19.51	19.33	33.23	19.61	17.20	12.43
Corynebacteria	9.76	8.75	15.99	1.05	9.11	1.78
Spore former rods	4.88	1.82	17.55	13.51	3.04	3.20
Coccus	28.05	28.57	21.32	19.17	38.54	28.95
Diplococcus	13.41	9.12	9.40	4.46	11.64	8.88
Sarcina	2.44	2.31	–	0.89	11.64	3.02
Staphylococcus	–	7.29	4.39	–	4.64	2.13
Micrococcus	7.32	9.85	7.52	9.36	4.55	8.53
Streptococcus	4.88	–	–	4.46	6.07	6.39
Gram-negative genera						
Rods	37.80	41.52	11.91	46.66	32.12	46.54
Acinetobacter	12.20	9.79	1.25	0.89	3.04	1.24
Alcaligenes	3.66	4.38	0.78	6.24	2.02	4.44
Enterobacter	4.88	12.77	9.87	4.46	12.65	16.34
Klebsiella	2.44	1.09	–	7.13	1.52	2.49
Escherichia coli	7.32	1.46	–	7.44	1.77	4.97
Pseudomonas	7.32	12.04	–	20.51	11.13	17.05

– Not found

Table 5 Percentages of airborne culturable fungal genera isolated from various environments in the Chong Chom border market

Genus	Outdoor	Indoor footpath	Wooden handicraft shop	Electronic shop	Secondhand clothing shop	Fruit market area
Acremonium	6.25	4.76	14.04	1.93	9.80	9.80
Absidia	–	2.38	–	–	1.09	1.96
Alternaria	31.25	7.14	–	1.93	2.18	3.92
Aspergillus	18.75	27.38	42.13	27.03	33.77	17.65
Chaetomium	–	5.95	2.81	–	5.72	1.96
Cladosporium	6.25	10.71	11.24	3.86	8.88	3.92
Fusarium	–	3.57	–	–	1.36	5.88
Mucor	–	5.95	–	–	4.52	9.80
Penicillium	25.00	23.81	19.66	62.74	25.05	15.69
Paecilomyces	–	4.76	4.49	–	2.18	7.84
Rhizopus	6.25	2.38	2.81	–	3.27	15.69
Sporotrichum	6.25	1.19	2.81	2.51	2.18	5.88

– Not found

samples, *Acremonium*, *Aspergillus* and *Cladosporium*, and *Penicillium* and *Sporotrichum* were the prevailing genera in all sampling sites. The indoor to outdoor ratios (I/O) for airborne microorganisms were in the range of 1.23–8.45. Extremely high values of airborne Gram-positive, Gram-negative

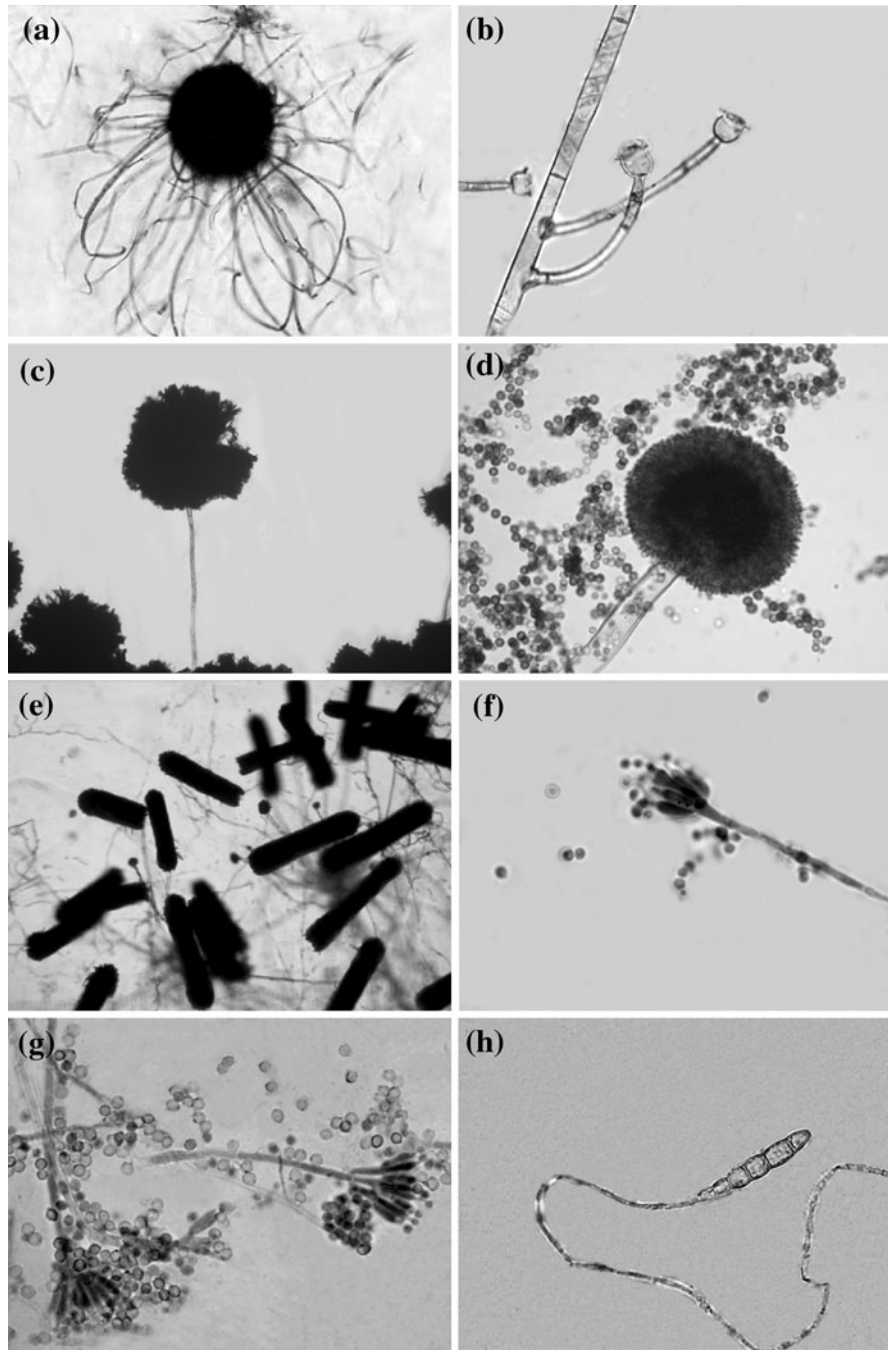


Fig. 1 Dominant airborne fungi found at various environments in the Chong Chom border market, Thailand; **a** *Chaetomium murorum* (100×); **b** *Mucor circinelloides* (100×); **c** *Aspergillus* sp., Sect Wentii (4×); **d** *Aspergillus niger* (40×); **e** *Aspergillus* sp., Sect. Clavati (10×); **f** *Paecilomyces* sp. (100×); **g** *Penicillium* sp. (100×); **h** *Alternaria* sp. (40×)

bacteria, and fungi were at indoor footpath (6.29), fruit market (8.45), and indoor footpath (5.25) areas, respectively. In this study, the ratio of airborne microorganism concentration inside and outside border market (I/O ratio) was larger than 1.00. All samples indicated that air quality may not be healthy in the market (Table 6). These I/O ratios also clearly showed that indoor footpath and fruit market areas

Table 6 The I/O ratio (the indoor/outdoor concentration ratio) for investigated various environments in the Chong Chom border market

Locations	Indoor (I)/outdoor (O) ratios		
	Gram-positive bacteria	Gram-negative bacteria	Fungi
Indoor footpath	6.29	7.34	5.25
Wooden handicraft shop	5.51	1.23	2.23
Electronic shop	2.35	3.38	3.26
Secondhand clothing shop	5.26	4.10	5.74
Fruit market area	5.90	8.45	3.19

I/O $\leq$ 1.5 good; I/O = 1.5 up to 2 regular; I/O > 2 poor (Stryjakowska-Sekulska et al. 2007)

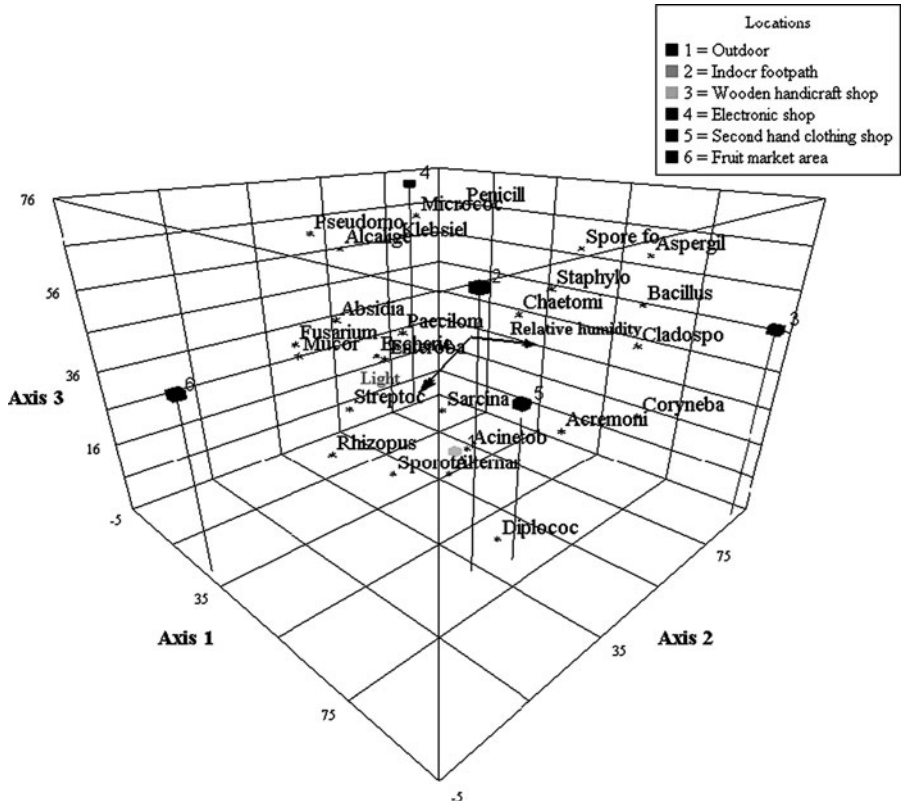


Fig. 2 Airborne microorganism distribution at various environments in the Chong Chom border market by PCA

were the major potential sources of biocontaminants. The results in this study also showed the distribution of aerosol microorganisms at various environments (Fig. 2). The principal component analysis (PCA) demonstrated that samples clearly discriminated along relative humidity and light factors. The wooden handicraft shop was classified toward the right end of the second axis, while the fruit market area was positioned toward the left endpoint of the first axis, indicating differentiation between fruit market area and wooden handicraft shop. Two variables, mainly responsible for this differentiation, were light and relative humidity. *Bacillus*, *Corynebacteria*, Spore former rods, and *Staphylococcus* positively correlated with relative humidity, while *Sarcina*, *Staphylococcus*, *Acinetobacter*, *Enterobacter,* and *Escherichia coli* positively correlated with light factor. Most of aerosol fungi exhibited positive correlation with light especially, *Absidia*, *Alternaria*, *Paecilomyces*, *Rhizopus*, and *Sporotrichum*. Four genera of fungi, *Acremonium*, *Aspergillus*, *Chaetomium*, and *Cladosporium*, showed positive correlation with relative

humidity. These results were also confirmed by Pearson correlation analysis. A significant correlation ($P < 0.01$) was found in the genus *Sarcina* ($r = 0.960$) with light factor, which indicates that there is a good positive correlation. Pearson correlation coefficient (r) between relative humidity parameters was found to be positively correlated with *Alternaria* ($r = 0.824$, $P < 0.05$), while *Aspergillus* was detected to be negatively correlated ($r = -0.849$, $P < 0.05$).

4 Discussion

Meteorological variables and airborne microorganisms inside the border market varied among different work environments. Significant differences ($P < 0.05$) were observed in the amount of light and the counts of airborne concentrations, Gram-positive bacteria, Gram-negative bacteria, and fungi collected by sedimentation and impingement methods among locations. Bacteria counts were influenced only by temperature, while aerosol fungi correlated to temperature and relative humidity. These results are in agreement with several studies that reported that the average concentration of airborne microorganisms varied with the presence of people (Van Houdt et al. 2009), tourists (Wang et al. 2010), indoor activities (Awad et al. 2010), and domestic climatic factors temperature and relative humidity (Kakde et al. 2001; Sen and Asan 2009; Zhao and Wu 2009; Basilico et al. 2007). The airborne concentrations in the Chong Chom border market, Thailand, were significantly higher compared to those in other cities in the world reported (El-Morsy 2006; Van Houdt et al. 2009; Aydogdu et al. 2010; Liu et al. 2010; Di Giulio et al. 2010), reflecting the tropical condition, high relative humidity, and temperature year round. High humidity and temperature provide a favorable environment for the proliferation of airborne microorganisms (Zuraimi and Tham 2008; Vasiliauskas et al. 2005).

This study found distinct prevalence of Gram-positive and Gram-negative aerosol bacteria in air samples, which is in accordance with many other studies (Awad 2007; Awad et al. 2010; Aydogdu et al. 2010; Dutkiewicz et al. 2000; Fang et al. 2007). Gram-positive bacteria, particularly the cocci (e.g., *Staphylococcus* and *Micrococcus*), are an indication of overcrowding and inadequate ventilation (ACGIH 1989; Awad 2007). These genera are found in almost all locations of Chong Chom border market, especially at the indoor footpath area. It seems probable that the cause may come from the people from all walks of life doing many activities there. Aydogdu et al. (2010) found that the cocci are widespread in nature and can be isolated from commensal inhabitants of the skin, mucous membranes, and other body sites in human and animals and also were regarded as potential immunotoxins.

For Gram-negative bacteria, they were found at the fruit market area (45.84% of total airborne microorganisms). Many researches have been found that Gram-negative bacteria normally are in lower count between 1 and 5% both indoor and outdoor environments (Aydogdu et al. 2010; Fang et al. 2007). In this study, Gram-negative bacteria were highly distributed in the border market because of many in local and wild plants and foods. Liu et al. (2010) and Awad et al. (2010) found that Gram-negative bacteria are related with agricultural environments. The presence of Gram-negative bacteria may increase health risk because they possess strong allergenic and endotoxic properties. Endotoxins can cause acute toxic effects, fever, malaise, and decreased pulmonary function (Prospero et al. 2005; Nilsson et al. 2011).

The predominance of airborne fungi as *Aspergillus*, *Cladosporium,* and *Penicillium* is in agreement with many studies reported that these genera were the dominant species in the working environments (Awad 2005; Dungan and Leytem 2009; El-Morsy 2006; Kakde et al. 2001; Li and LaMondia 2010), home (Garrett et al. 1997; Kasprzyk and Worek 2006; Nasir and Colbeck 2010), school (Aydogdu and Asan 2008) and hospital (Obbard and Fang 2003; Takeda et al. 2009). In addition, a vast number of airborne fungi found in Chong Chom border market such as *Cladosporium*, *Alternaria*, *Aspergillus,* and *Penicillium* have been identified in the medical literature as being implicated in allergic disease (Sen and Asan 2009) and induced acute intoxication and many adverse effects to human health as carcinogenic, mutagenic, teratogenic, hormonal, hemorrhagic, immunotoxic, nephrotoxic, hepatotoxic, dermatoxic, neurotoxic, antibiotic, hematological changes, releasers of interleukins, and lipid peroxidation (Anttila 2000; Cabral 2010).

The indoor-to-outdoor ratios pointed out that the potential contamination source of biocontaminants was indoor, especially indoor footpath, fruit market area, and secondhand clothing shop. Indoor footpath is area of heavy traffic flow, crowded with the people from all walks of life. Fruit market area consists of many local, wild, and agricultural products, and the secondhand clothing shop is the store of natural and artificial textiles, which is the major habitat of microfungi. These areas were the major aerosol pathogens of the Gram-positive bacteria, Gram-negative bacteria, and fungi. The results also indicated that airborne microbial counts exceeded the proposed value of 5–10 $\times$ 10^3 CFU $m^{-3}$of total microorganisms for occupational environments (Awad 2007). Therefore, airborne microorganisms in the border markets are at inadmissible level, and some preventive actions should be proposed.

The plots obtained by PCA technique also demonstrated relative humidity, and light intensity influencing on the distribution of microorganisms is in agreement with the work of Lighthart et al. (2009). The results also revealed that *Aspergillus* was most heterogeneous while *Chaetomium*, *Penicillium*, *Cladosporium*, and *Alternaria* were distributed in specific environments indoor footpath, electronic shop, wooden handicraft shop, and secondhand clothing shop, respectively. These are the major genera of aerosol indoor fungi and act as mycotoxin and secondary metabolite producers (Piecková and Jesenská 1998; Fabian et al. 2005; Anttila 2000; Nilsson et al. 2004). In addition, exposure to large concentrations of the spores of four genera *Aspergillus*, *Penicillium*, *Cladosporium*, and *Alternaria* causes aspergillosis (Anderson et al. 1996).

5 Conclusion

The study of airborne concentrations of bacteria and fungi in the Chong Chom border market, Thailand, indicated that the border market is a potential source of aerial transmission and a various hazards of bioaerosols on workers, consumers, and sellers as well as on the market commodities. The bioaerosol concentration exceeded the standard of occupational exposure limit, WHO, ACGIH, NIOSH, OSHA, and AIHA identified with I/O ratio. Many major indicators of allergenic and toxigenic airborne bacteria and fungi were found in the various market environments such as *Acinetobacter*, *Enterobacter*, *Pseudomonas*, *Cladosporium*, *Alternaria*, *Aspergillus,* and *Penicillium*.

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