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ASSESSMENT OF HUMAN EXPOSURE TO AIRBORNE FUNGI IN AGRICULTURAL CONFINEMENTS: PERSONAL INHALABLE SAMPLING *VERSUS* STATIONARY SAMPLING

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Abstract: Accurate exposure assessment to airborne fungi in agricultural environments is essential for estimating the associated occupational health hazards of workers. The objective of this pilot study was to compare personal and stationary sampling for assessing farmers' exposure to airborne fungi in 3 different agricultural confinements located in Ohio, USA (hog farm, dairy farm, and grain farm), using Button Personal Inhalable Samplers. Personal exposures were measured with samplers worn by 3 subjects (each carrying 2 samplers) during 3 types of activities, including animal feeding in the hog farm, cleaning and animal handling in the dairy farm, and soybean unloading and handling in the grain farm. Simultaneously, the stationary measurements were performed using 5 static Button Samplers and 1 revolving Button Sampler. The study showed that the total concentration of airborne fungi ranged from 1.4×10^4–1.2×10^5 spores m^{-3} in 3 confinements. Grain unloading and handling activity generated highest concentrations of airborne fungi compared to the other 2 activities. Prevalent airborne fungi belonged to *Cladosporium*, *Aspergillus*/*Penicillium*, Ascospores, smut spores, *Epicoccum*, *Alternaria*, and Basidiospores. Lower coefficients of variations were observed for the fungal concentrations measured by personal samplers (7–12%) compared to the concentrations measured by stationary samplers (27–37%). No statistically significant difference was observed between the stationary and personal measurement data for the total concentrations of airborne fungi ($p>0.05$). Revolving stationary and static stationary Button Samplers demonstrated similar performance characteristics for the collection of airborne fungi. This reflects the low sensitivity of the sampler's efficiency to the wind speed and direction. The results indicate that personal exposure of agricultural workers in confinements may be adequately assessed by placing several Button Samplers simultaneously operating in a static stationary mode throughout the work site.

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INTRODUCTION

Agricultural workers are at increased risk of occupational respiratory diseases [33]. The role of airborne fungi for developing the respiratory allergy and asthma has been established by previous studies [17, 32, 42]. More than 80 genera of fungi have been associated with respiratory tract allergy [22, 29]. Several fungi isolated from the air have been reported to produce mycotoxins, such as aflatoxins, ochratoxin, and

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trichothecenes [12, 19]. Furthermore, people with immune deficiencies are at risk of infection from airborne fungi in occupational environments [19]. Large quantities of fungi can be released into the air from the activities in different agricultural environments, such as swine confinements [8, 36, 38], dairy sheds [3, 14, 21], and grain loading and handling sites [27, 28, 35, 43].

Most of the previous research on airborne fungi in different agricultural environments utilized only culture-based sampling methods [8, 14, 36, 38, 43]. Thus, these studies ignored the non-culturable airborne fungi, which may be as allergenic or toxigenic as the culturable fungi [18], and thus cause health hazards for agricultural workers. Kozak *et al.* [26] showed that although the concentration of culturable airborne fungi can be below the detection limit of established culture-based sampling methods, the total concentration of airborne fungi may be sufficiently high to initiate a respiratory health hazard. The limitations of culture-based methods also include the loss of culturability by impaction stress in samplers, failure of different laboratory culture media to support fungal growth (mostly for fungi that belong to Ascomycetes and Basidiomycetes classes), and the antagonistic interactions between different fungi, as well as between fungi and other microorganisms that inhibit the fungal colonization. Moreover, the traditional culture-based methods can typically be used at sampling time as short as a few minutes. Otherwise, the collection media may be overloaded as the aerosol concentration is usually very high. Liquid impingers can be used for longer sampling periods; however, a non-evaporating liquid is necessary which will not affect the viability of fungi [30]. Moreover, this method cannot be used directly for the analysis of total airborne fungi. This information indicates a clear need for implementation of test methods that would allow long-term sampling of total culturable and non-culturable fungi in agricultural environments.

Because of the presence of multiple sources of fungal growth and different types of activities affecting the dispersal of fungi in the air, the spatial variation of the airborne fungal concentration is likely to be high in agricultural environments. This variability has not been addressed in most of the earlier studies on the exposure to airborne fungi in grain handling places [25, 35, 43], swine houses [8, 38], and cattle sheds [1, 3], because the measurements were primarily conducted by a single stationary sampler collecting airborne fungi. Thus, more data are needed on the spatial variation of the airborne fungal concentration in different agricultural environments to better understand the workers' exposure patterns to airborne fungi.

To determine the risk of health effects caused by airborne fungi in agricultural confinements, the measurements should be performed in a way that properly reflects the human exposure. Renström's review [40] indicated that airborne allergen results obtained by stationary sampling are usually significantly lower than those obtained by personal sampling. Rautiala *et al.* [38] investigated the concentration of airborne culturable fungi using personal and stationary sampling during remediation of moldy buildings. Their study also revealed that the level of culturable fungi was higher in personal samples than in stationary samples, as was measured in 2 out of 3 construction sites tested by the investigators. A similar conclusion was made by Toivola *et al.* who compared personal and stationary sampling data collected in home and work environments [44]. Since the literature is not conclusive about personal versus stationary measurements of airborne fungi, particularly in agricultural environments, further study seems to be worthwhile.

Any change in the work environment may significantly affect workers' exposure [9] that can be tracked through personal aerosol monitoring. However, personal samplers have rarely been used for measuring exposure to airborne fungi in agricultural environments. Among the few examples, Swan and Crook [43] used a single personal aerosol monitor for collecting airborne fungi during grain handling activity, but this personal sampler operated in a stationary mode. Radon *et al.* [37] studied personal exposure to airborne fungi in different European agricultural environments using air-monitoring cassettes, but not the inhalable sampling method. The lack of personal exposure data in agricultural settings may be due to workers' reluctance to carry the personal sampling equipment. It is evident that more knowledge is needed about the pros and cons of the use of personal sampling techniques in agricultural environments contaminated with airborne fungi.

To respond to the above-described knowledge gaps, we studied farmers' exposure to airborne fungi by using several stationary and personal samplers operated in parallel. The measurements were conducted in 3 different agricultural confinements (hog, dairy, and grain farms) using the Button Personal Inhalable Samplers (SKC, Inc., Eighty Four, PA, USA). This sampler allows performing long-term sampling with the subsequent analysis for total airborne fungi.

MATERIALS AND METHODS

Agricultural confinements. The hog farm selected for this investigation located at the Ohio Agricultural Research and Development Center, Western Branch, near South Charleston, Ohio, USA. The workers performed various tasks in the swine operation, including animal feeding, working with the piglets in the nursery, and interacting with the mother pigs in the furrowing room as well as with the animals in the breeding area. The chamber (7 m × 10 m) designated for the feeding activities of matured animals was selected for the measurements. The floor of the sampling site was wet and faecal material and urine of swine were present. The farm was situated in an open agricultural field area, and 2 sides of the confinement were open. To ensure sufficient ventilation, several electric fans were in operation. Automatic

sprayers sprayed water in every few minutes to cool the pigs directly. The livestock food storage place located close to the sampling site. A musty odour was observed in this place, which may be due to fungal or bacterial growth in rotting organic materials.

The dairy farm was located in an agricultural field near Ottawa, Ohio, USA. Workers were involved in cleaning, adding grinded soil as bedding material, animal feeding, and milking activities during the sample collection. The central area (30 m × 100 m) designated for the distribution of livestock foods to animals, accommodating approximately 600 cows, was selected for the air sampling. The floor of the sampling site was mostly wet. Faecal material and urine of animals were regularly cleaned and transported to a compost plant. A musty odour from rotting livestock foods and hay was present.

The grain unloading and handling site was situated near an agricultural farm at Clarksville, Ohio, USA. The samples were collected at the time of soybean unloading from a truck to a silo. The size of the unloading area, including the silo, was approximately 30 m × 20 m. The grain handling generated a high concentration level of dust in the air (3.6×10^6 particles m^{-3} in the particle size range of 0.7–10 µm).

Aerosol sampling method. For measuring human exposure to airborne fungi, a personal sampler that follows the ACGIH/CEN/ISO inhalable sampling convention [6, 11, 23] is the best option because the exposure measured by this sampler represents the inhalable fraction of the airborne fungi [24]. The features of the personal inhalable sampling in assessing the exposure to aeroallergens, including airborne fungi, has been described in detail in our previous study [2]. In this study, personal and stationary samples were collected using the Button Personal Inhalable Sampler in all sampling sites. As a filter collector, this device is efficient for capturing relatively small airborne particles, such as fungi. The inlet of the Button Sampler is made by a portion of a spherical shell with evenly placed numerous orifices (381 µm). The screen area of the inlet is 19.6 cm^2 and its total porosity is 21%. The sampler can be operated in both stationary and personal modes. Based on the data obtained under the laboratory conditions, Aizenberg *et al.* [4] reported that there is no significant difference between the sampling efficiencies of the Button Sampler in the stationary and personal modes. Because of this important feature, it is feasible to explore a stationary sampler with respect to its suitability for personal exposure assessment. For the purpose of comparing stationary and personal samplers, fungal spores can be expected to behave similarly to other airborne particles.

The sampling efficiency of the Button Sampler closely follows the inhalability convention of ACGIH, CEN, and ISO [5]. The particles are deposited primarily on a filter area of approximately 380 mm^2 (22 mm diameter). This large area of deposition is advantageous when the sampling is performed at highly contaminated agricultural confinements. Samplers with smaller particle collection areas (for example, one hour sampling into the moving sampling surface of the 7-day Burkard Sampler creates a deposit on the area as small as 28 mm^2) may not be suitable because of overloading of their collectors with airborne dust and bioaerosol particles. In the present study, mixed cellulose ester (mixture of cellulose acetate and cellulose nitrate) membrane filter of 1.2 µm pore size (Millipore Corp., Bedford, MA, USA) was used for the fungal sampling. Samples were collected at a flow rate of 4 L min^{-1} continuously for 1 hour using a personal pump. The pumps made by 2 manufacturers, SKC Inc. (Eighty Four, PA, USA) and BGI Inc. (Waltham, MA, USA), were used for the field tests. Sample preparation and mounting followed by field experiments were performed using the protocol described by Adhikari *et al.* [2].

Microscopic analyses of fungi. Forty randomly selected microscopic fields were analyzed in each sample using a Nikon (Labophot 2, Nikon Corp., Japan) high-resolution light microscope. In each field, fungal spores were counted and identified to the genus/class level. Identification was based on reference slides (Aerobiology Instruction and Research, Brookline, MA, USA) and on the illustrated identification manuals by Smith [41] and Ellis [17]. The magnification of ×400 was used, except when the spores were not identifiable or the deposition was too dense. In these cases the magnification of ×1,000 was applied. Phase contrast objectives were utilized to identify unpigmented hyaline spores. A variation in spore counting precision was reported by Eduard and Aalen [16] because of the spore aggregates and uneven distribution of spores on filter surfaces. Spore aggregation was not an important concern during our microscopic analysis possibly because of the uniform particle deposition facilitated by the inlet characteristics of the Button Sampler. Occasionally, spore and dust aggregates were observed in the samples from grain farm. However, using ×1,000 microscopic magnification the spores were countable.

The spore counts were converted to airborne concentrations following the protocols used in our previous study [2]. The detection limit of microscopic analysis was 273 spores m^{-3}.

Sampling procedure and strategies. The measurements at the 3 farms were performed in different days. Both personal and stationary measurements were performed during 1 hour in the hog farm and the dairy farm. For the grain farm, the sampling time was 30 minutes. The sampling periods were selected based on the durations of working activities. Samples were collected at the time of animal feeding in the hog farm, cleaning and animal handling in the dairy farm, and soybean handling in the grain farm. Personal exposures to airborne fungi were measured for 3 subjects at each site carrying 6 Button Personal Inhalable Samplers (2 samplers were attached at the chest of each person). During the sample collection

the subjects were involved in different work activities around the sampling site. Simultaneously to the personal exposure measurements, the concentrations of airborne fungi were measured using stationary Button Samplers. Five simultaneous stationary measurements in all sampling sites were performed to address the spatial variability of airborne fungi in the confinements. Four of them were placed within 1 m from the corners of the sampling site and 1 sampler was at the centre. All samplers in corners were oriented towards the centre of the sampling site, and the central sampler was oriented towards the prevalent wind direction in the area.

Low sensitivity of the sampling efficiency to the wind direction and speed is essential for a personal sampler. Although the Button Sampler demonstrated this feature under controlled laboratory conditions with non-biological particles [4] and under outdoor field conditions when used for the collection of airborne fungi [2], its sensitivity to the wind direction and speed has not been tested in agricultural confinements where airborne fungal spores can be aggregated with each other, as well as with dust generating bioaerosol particles of a larger size. In this study, we compared the data obtained with identical samplers in stationary mode, including several static devices and the device operating in the revolving regime. This comparison allowed us to evaluate the wind direction and speed as factors that potentially affect the performance of the Button Sampler in mould-contaminated agricultural environments. The revolving regime of the Button Sampler operation is a modification of the methodology used in our earlier field study [2] in which 2 samplers were oriented opposite to each other. Thus, in addition to samples collected with 5 stationary static Button Samplers, 1 sample was collected in each experiment with a revolving Button Sampler placed near the central stationary sampler. This Button Sampler was placed on a revolving stand connected to a large vane that maintained the inlet of the sampler oriented against the wind. All samplers were placed at the height of 1.4 m, representing the breathing zone elevation.

Statistical analyses. Non-parametric statistics was employed because the number of observations per experiment did not exceed 6 and the normal distribution of the data could not be achieved. Mann-Whitney test and Wilcoxon signed ranks test were performed using the SPSS 11.0 for Windows software (SPSS Inc., Chicago, IL, USA). The p values of <0.05 were considered as significant.

RESULTS AND DISCUSSION

Airborne fungi measured with stationary sampling. The stationary measurements revealed the following ranges of total airborne fungi: $(1.4–3.3) \times 10^4$ spores m^{-3} at the hog farm, $(3.2–7.1) \times 10^4$ spores m^{-3} at the dairy farm, and $6.7 \times 10^4–1.2 \times 10^5$ spores m^{-3} at the grain farm. Thus, grain unloading and handling activity generated the highest concentrations of airborne fungi, followed by cleaning and animal handling at the dairy farm and animal feeding at the hog farm. The mean airborne fungal concentrations and standard deviations measured by stationary samplers in 3 confinements are presented in Table 1. The number of observations was 5 in hog farm and dairy farm. For the grain farm we had 3 samples because of the malfunctioning of 1 pump and loss of 1 sample during mounting. Overall, 10 different fungal genera/classes were identified in the stationary samples from all the tested confinements. *Cladosporium* and *Aspergillus*/*Penicillium* were the most prevalent fungi in all 3 farms. These fungi comprised altogether about 71–85% of the total concentration. Other prevalent fungi (>3%) included Ascospores, *Alternaria*, Basidiospores, and *Epicoccum*. Among the farms, the greatest diversity of species was measured at the hog farm. Approximately 2–4% of the total airborne fungi remained unidentified and was grouped under the category of 'unknown fungi'.

Among the fungal genera found in the confinements, *Cladosporium*, *Aspergillus*/*Penicillium*, and *Alternaria* are strongly associated with allergic respiratory disease, especially asthma [13]. Smuts of common cereal grains and grasses and *Epicoccum* are also important aeroallergens [7, 34]. Thus, many of the airborne fungi that were present in the confinements can potentially cause health hazards for the workers.

Most of the recent studies investigated only culturable fungi in swine buildings. When comparing our results on the total concentration (spores m^{-3}) to the earlier findings on the culturable count (cfu m^{-3}), it appears that our hog farm data were approximately 10-fold higher than those reported by Mackiewicz from Lublin, Poland [31], Chang *et al.* from Taipei, Taiwan [8], and Predicala *et al.* from Kansas, USA [36]. At the same time, Crook *et al.* from Northern Scotland [10] and Rautiala *et al.* from Kuopio, Finland [38], observed culturable fungi concentrations as high as 10^5 cfu m^{-3} in swine confinement buildings. Eduard [15] reviewed previous studies on the culturable airborne fungi in pig houses and reported a concentration range of $10^3–10^5$ cfu m^{-3} measured by different researchers.

Our data collected in dairy farms were approximately 10 times higher than the total airborne fungi concentration levels reported by Adhikari *et al.* from India [3], but about 10 times lower than the data reported by Hanhela *et al.* from Finnish cow barns [21]. The culturable airborne fungi measured by Duchaine *et al.* in dairy farms of Quebec, Canada [14] was as high as 10^6 cfu m^{-3}.

We found 2 reports on total airborne fungi measured during grain handling activity. Pandit *et al.* [35] found rich airborne mycoflora in a grain store in Delhi, India; however, the total airborne concentrations were about 10 times lower than in our study. On the other hand, the total concentrations of airborne fungi on Finnish farms, $10^5–10^7$ spores m^{-3}, reported by Lappalainen *et al.* [28] were higher than the levels measured in our study. These contrasting observations of airborne fungal concentrations

Table 1. Mean, standard deviation, and coefficient of variation (CV) of the concentration of airborne fungi (spores m^{-3}) measured by stationary samplers in three agricultural confinements.

Name of fungi	Concentration of airborne fungi (spores m^{-3})		
	Hog farm (n = 5) Mean ± SD	Dairy farm (n = 5) Mean ± SD	Grain farm (n = 3) Mean ± SD
Aspergillus/*Penicillium*	8067 ± 3020	8830 ± 1384	37610 ± 12818
Alternaria	727 ± 315	545 ± 510	3452 ± 3002
Ascospores	3816 ± 2445	1363 ± 1124	4542 ± 2743
Basidiospores	709 ± 244	1145 ± 591	1090 ± 545
Cercospora	55 ± 122		
Cladosporium	8449 ± 4029	27581 ± 13613	31615 ± 9827
Epicoccum	109 ± 149	109 ± 149	1272 ± 2203
Fusarium	55 ± 122		
Smut spores	600 ± 524	763 ± 299	6904 ± 3330
Torula	68 ± 136		
Unknown fungi	927 ± 311	981 ± 531	3816 ± 944
Total concentration	23275 ± 6840	43007 ± 15734	95025 ± 25938
CV (%) of total concentration	29	37	27

Table 2. Mean, standard deviation, and coefficient of variation (CV) of the concentration of airborne fungi (spores m-3) measured by personal samplers in three agricultural confinements.

Name of fungi	Concentration of airborne fungi (spores m^{-3})		
	Hog farm (n = 6) Mean ± SD	Dairy farm (n = 6) Mean ± SD	Grain farm (n = 5) Mean ± SD
Aspergillus/*Penicillium*	7586 ± 1666	8630 ± 2171	36738 ± 4651
Alternaria	654 ± 413	545 ± 431	4361 ± 2698
Ascospores	2135 ± 1174	2226 ± 529	4252 ± 1411
Basidiospores	908 ± 372	1181 ± 281	654 ± 711
Cercospora	45 ± 111		
Cladosporium	11628 ± 2680	21349 ± 4859	20059 ± 9269
Epicoccum	91 ± 141	45 ± 111	872 ± 1950
Fusarium	55 ± 122		
Smut spores	409 ± 286	1181 ± 410	9048 ± 1791
Torula	136 ± 228		
Unknown fungi	954 ± 615	872 ± 756	4797 ± 3391
Total concentration	24483 ± 2963	37065 ± 4046	89175 ± 6174
CV (%) of total concentration	12	11	7

in agricultural environments of different countries can be attributed to the different structures of the agricultural confinements, diverse local sources for fungal growth in different climates, environmental parameters, and activities of farm workers. The animal confinements tend to be more enclosed in colder climates, such as in Canada, Scotland, and Finland, and less enclosed in warmer climates, such as in India (compared to ones in the Midwest USA). The association of airborne fungal exposure with these factors needs further investigation.

The concentration of airborne fungi in agricultural confinements is expected to exhibit considerable spatial variation because of the spatial variation in fungal growth substrates and activities. The coefficients of variations (CV, %) of the concentrations measured by several simultaneously operating stationary samplers in 3 confinements are presented in Table 1. The CV of the concentrations in the dairy farm (37%) was higher compared to the hog farm (29%) and grain farm (27%). This observation can be attributed to the larger size of the dairy farm compared to the 2 other sites. The CV values in all 3 confinements, however, were rather high, suggesting that multiple samples are preferable over a single sample to achieve representative exposure data when using stationary sampling. High CV values can be attributed to the diversity of local sources of airborne fungi in agricultural confinements, different activities (of both workers and animals) performed in these settings, relatively low wind speed (enhancing the spatial variability), and significant distances between the stationary samplers and the sources. We found that the samplers positioned near the centre consistently recorded higher levels of airborne fungi than the 4 samplers in the corners [hog farm: central = 3.3×10^4 spores m^{-3} and corner samplers = $(1.4–2.6) \times 10^4$ spores m^{-3}; dairy farm: central = 7.1×10^4 spores m^{-3} and corner samplers = $(3.2–3.8) \times 10^4$ spores m^{-3}; grain farm: central = 1.2×10^5 spores m^{-3} and corner samplers = $6.7 \times 10^4 – 1.0 \times 10^5$ spores m^{-3}]. This finding confirms the effect of local fungal sources on the spatial variability of the airborne concentrations of fungi. Although these sources and the working procedures were not investigated and characterized in our study, we observed several of those, which likely represent the major contributions: the storage of livestock foods, stacks of hay, raw and decomposing faecal material and livestock foods, ground up soil as bedding material in the dairy farm, and drainage of the compost plant.

Airborne fungi measured with personal sampling. Similar to the results obtained by stationary samplers, the highest range of personal exposure to airborne fungi was observed in the grain farm [$(7.8–9.3) \times 10^4$ spores m^{-3}] followed by the dairy farm [$(3.3–4.3) \times 10^4$ spores m^{-3}] and the hog farm [$(2.0–2.8) \times 10^4$ spores m^{-3}]. Means and standard deviations of personal exposure data are presented in Table 2. The species of the airborne mycoflora observed in the personal samples were the same as in the stationary samples. *Cladosporium* and *Aspergillus*/*Penicillium* were the most predominant fungi comprising 63–80% of the total concentration. In addition to *Cladosporium* and *Aspergillus*/*Penicillium*, Ascospores and Basidiospores were prevalent (>3%) in the hog farm. Smut spores in the dairy farm as well as Smut spores and *Alternaria* in the grain farm also showed a prevalence of >3%.

To evaluate the precision of measurement procedure, we compared the total spore concentration data obtained from the pair of samplers worn by an individual worker using Wilcoxon signed ranks test. No statistically significant difference was observed ($p = 0.5$) indicating that the measurement procedure was adequately precise.

To our knowledge, no previous study has addressed the exposure of workers to airborne fungi in agricultural confinements through the measurements conducted with personal inhalable samplers. Thus, this investigation may serve as a pilot study to quantify the levels of airborne fungi which can be inhaled by the workers during different agricultural activities.

The coefficients of variations of the concentrations measured by several simultaneously operating personal samplers are presented in Table 2. Low CV values ranging from 7–12, indicate that the levels of personal exposure to airborne fungi were very similar between the 3 subjects working simultaneously in the same confinement. This finding can be attributed to the frequent movement of the subjects during the sample collection, which enabled them to receive relatively uniform exposure in spite of the spatial variability caused by local sources of fungi.

Stationary measurement versus personal measurement (2 approaches for assessing the human exposure to airborne fungi). The comparison of the total concentrations of total airborne fungi measured by stationary and personal samplers, respectively, is presented by Table 3. No significant difference between these concentrations was observed in any of the 3 confinements (Mann-Whitney test: $p > 0.05$). The concentrations (mean values and standard deviations) measured by stationary and personal samplers are compared schematically in Figure 1 for total airborne fungi and seven prevalent types (*Aspergillus*/*Penicillium*, *Alternaria*, Ascospores, Basidiospores, *Cladosporium*, Epicoccum, and Smut spores). The figure shows that the concentration levels measured by personal and stationary samplers for both total airborne fungi and individual fungal types are close to the 1:1 line. The value for *Aspergillus*/*Penicillium* lies exactly on the 1:1 line, which may be due to their smaller aerodynamic size (<5 µm) enhancing the uniform distribution of these fungi in personal and stationary samples.

The similarity of airborne fungal levels obtained in our stationary and personal exposure measurements are different from those found in the previous studies of Toivola *et al.* [44] and Rautiala *et al.* [38]. For culturable airborne fungi, Toivola *et al.* [44] reported higher concentration in the integrated personal samples as compared to microenvironment-specific stationary samples. Personal samples were collected for 24 hours from home, work, and other environments. For total airborne fungi, Toivola *et al.* [44] measured significantly higher concentrations in the work environment than the integrated personal exposure monitoring. Thus, the concentration measured by the personal sampler was diluted by the lower levels of airborne fungi in home and other environments compared to work environments. Rautiala *et al.* [38] also reported higher concentrations of culturable fungi measured by personal samplers than by stationary samplers during remediation of mouldy buildings. However, the investigators of that study used only 1 stationary sampler at each site, whereas we used 3–5 simultaneously operated samplers placed in the corners and at the centre of the confinement. To summarize, the different sampling strategies applied in our study and in the studies of Toivola *et al.* [44] and Rautiala *et al.* [38] explain the difference between the results. Based on the studies of Toivola *et al.* [44] and Rautiala *et al.* [38], we can anticipate that the concentration measured by stationary and personal samplers may differ if the workers perform their work tasks in different sections of the work area, while the stationary samples are collected only in 1 central location.

Table 3. Comparison between the concentrations of total airborne fungi (spores m^{-3}) measured by stationary and personal samplers in three agricultural confinements.

Agricultural confinement	Concentration of airborne fungi (spores m^{-3})		p*
	Stationary measurements, Mean ± SD	Personal measurements, Mean ± SD	
Hog farm	23275 ± 6840 (n = 5)	24483 ± 2963 (n = 6)	0.5
Dairy farm	43007 ± 15734 (n = 5)	37065 ± 4046 (n = 6)	0.7
Grain farm	95025 ± 25938 (n = 3)	89175 ± 6174 (n = 5)	0.4

*p value (Mann-Whitney test)

Since we did not find any statistically significant difference between the concentrations measured by stationary and personal samplers, the Button Personal Inhalable Sampler seems to be feasible for the use in a stationary mode for estimating the actual personal exposure of workers to inhalable airborne fungi in confined agricultural environments. As mentioned in the Introduction, exposure assessment studies in agricultural environments often suffer from lack of the worker's willingness to wear personal sampling devices. To help address this issue, we recommend using the Button Personal Inhalable Sampler in the stationary mode as an alternative to the personal sampling. However, while comparing the average total spore concentration data from personal samplers with the single central stationary sampler, we found 1.3–1.9 times higher concentration levels in the stationary sampler. For this reason, we recommend that several stationary Button Samplers are to be placed in the confinement for assessing the personal human exposure levels to inhalable airborne fungi.

Static stationary sampling versus revolving stationary sampling. Figure 2 presents the comparison of the concentrations of total airborne fungi and 7 prevalent fungal types measured by revolving and static stationary samplers, respectively. Since size of these fungi are

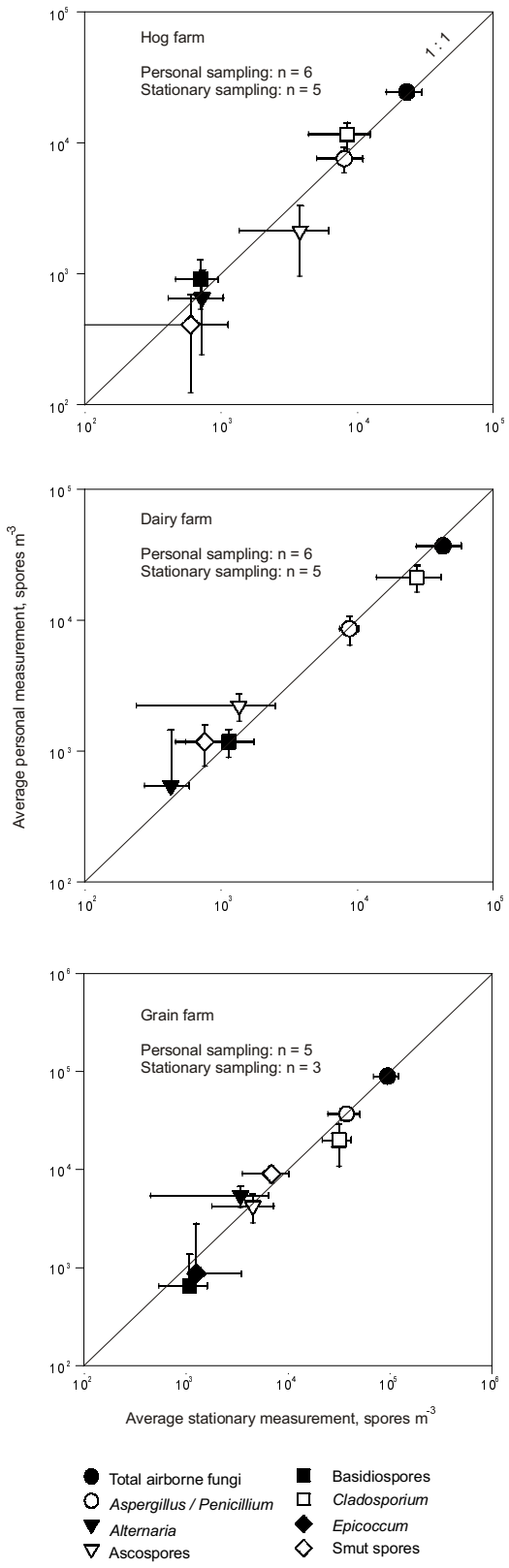

Figure 1. Comparison of the total concentration of airborne fungi measured by stationary and personal samplers in three agricultural confinements. The error bars represent standard deviations of spore concentrations in all measurements.

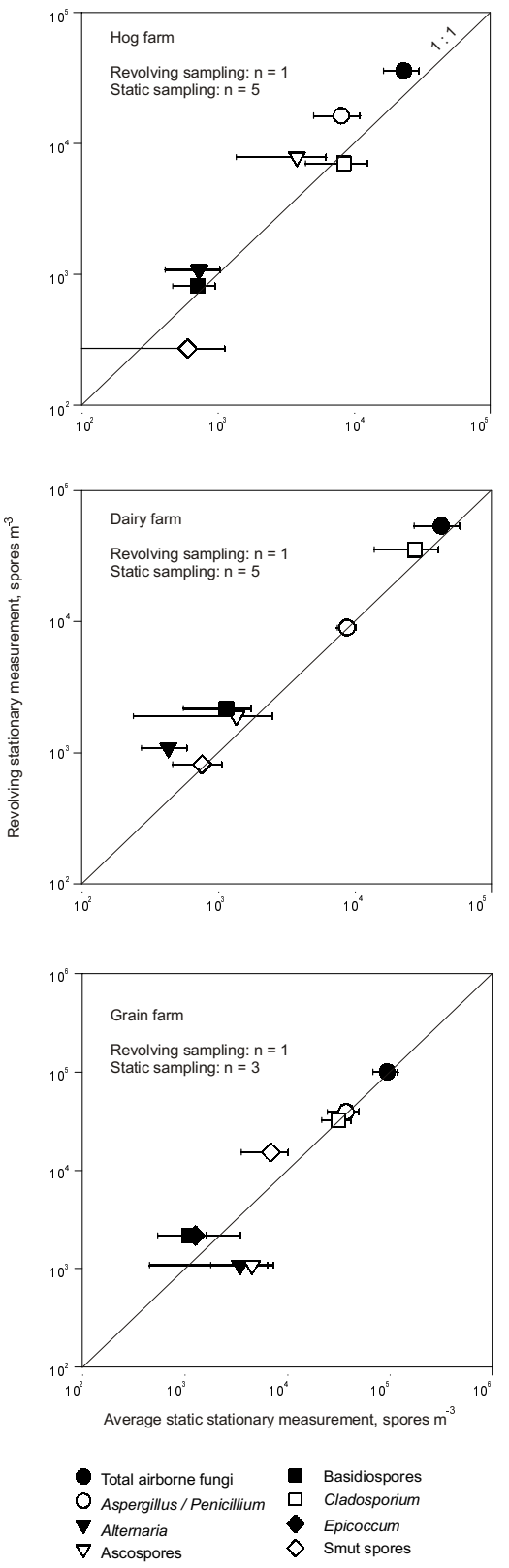

Figure 2. Comparison of the total concentration of airborne fungi measured by revolving stationary and static stationary samplers in three agricultural confinements. The error bars represent standard deviations of spore concentrations in all measurements.

different, we expected differences with reference to their wind sensitivity. The data points represent the average values and the error bars represent the standard deviations of measurements conducted by the static stationary samplers. No vertical error bars are shown as only 1 revolving sampler was used in each confinement. The figure shows that the concentration levels of total airborne fungi as well as individual types of fungi are close to the 1:1 line. This observation was more pronounced for the dairy farm and the grain unloading and handling site compared to the hog farm. The findings reconfirm the results of previous studies by Aizenberg *et al.* [4] and Adhikari *et al.* [2] that suggested that the concentration data generated by the Button Sampler exhibit low sensitivity to the wind direction and speed.

CONCLUSIONS

Several potentially hazardous airborne fungi were observed in 3 agricultural confinements; however, the airborne mycoflora did not exhibit rich diversity with only 10 fungal genera/classes identified. Grain handling activity generated the highest level of airborne fungi in both stationary and personal samples compared to the animal feeding activity in the hog farm, as well as to the cleaning and animal handling activity in the dairy farm. There was no statistically significant difference between the concentrations of airborne fungi measured by stationary and personal samplers in any of the 3 confinements. The revolving stationary Button Samplers demonstrated similar levels of airborne fungi as the static stationary Button Samplers in all confinements. Thus, it was confirmed that the Button Sampler has low sensitivity to the wind conditions in confined work environments. The Button Personal Inhalable Sampler was found suitable to be used in a static stationary mode for assessing the personal exposures to airborne fungi in confined agricultural environments. Several parallel samplers are needed throughout the confinement to account for the spatial variation. Further exposure assessment studies to airborne fungi seem to be worthwhile, in which the personal and stationary Button Samplers would be utilized to better address a variety of working procedures and exposure time periods occurring in different agricultural settings.

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