Mycol. Res. **109** (11): 1235–1242 (November 2005). © The British Mycological Society
doi:10.1017/S0953756205003953 *Printed in the United Kingdom.*

Release and dispersal of basidiospores from *Amanita muscaria* var. *alba* and their infiltration into a residence

De-Wei LI

The Connecticut Agricultural Experiment Station, Valley Laboratory, 153 Cook Hill Road., Box 248, Windsor, CT 06095, USA.
E-mail: *DeWei.Li@po.state.ct.us*

Received 30 March 2005; accepted 19 July 2005.

Release and dispersal of basidiospores of *Amanita muscaria* var. *alba* and their potential to infiltrate a nearby residence were investigated. Basidiospore release mainly occurred in the first three days following the expansion of the caps. The concentrations of released basidiospores near basidiomata were 77 137, 75 062, and 41 738 spores m^{-3} in the first three days, respectively, with the highest concentration at 281 738 spores m^{-3} air. After three days, the concentration dropped by 95 %. At the second location, airborne basidiospore concentrations dropped 96–99 % after three days with the concentrations of 940, 575, and 1359 spores m^{-3} in the first three days, respectively. The diurnal pattern showed a relatively extended night peak. Relative humidity and dew were positively correlated with basidiospore release and short distance dispersal. Rain and rain rate were positively correlated with basidiospore release, but not correlated with short distance dispersal. The basidiospore release period of *Amanita muscaria* var. *alba* was short, but within such a period it released a large amount of basidiospores. However, only less than 5 % of basidiospores released were dispersed to the second location 5.2 m away and 2.7 m above the basidiomata. Only <0.1 % of basidiospores dispersed from the basidiomata were found inside a nearby residence. *Amanita muscaria* var. *alba* showed a low potential of infiltrating the residence.

INTRODUCTION

Amanita muscaria is a widespread species developing ectomycorrhizas with pine, spruce, fir, larch, birch, and aspen in northern temperate zones and common in Europe, Asia, and North America (Mohan *et al*. 1995, Nehls *et al*. 2001). The var. *alba* is an uncommon variant infrequent in northern North America (Lindgren 1998). *Amanita muscaria* contains ibotenic acid and muscimol, which react with neurotransmitter receptors in the central nervous system (Chilton & Ott 1976, Tupalska-Wilczynska *et al*. 1997, Michelot & Melendez-Howell 2003). A distinctive syndrome including alternating phases of drowsiness and agitation with hallucinations, and sometimes with convulsions will be produced following ingestion of mushrooms of this species (Tupalska-Wilczynska *et al*. 1997). The cap of *A. muscaria* var. *alba* is 4–21 cm diam, convex to plane, white to slightly tan on disc and covered with warts; volva as concentric rings of universal veil tissue on a bulbous base (Lindgren 1998). During the fruiting season, basidiospores released from basidiomata of *Amanita muscaria* varieties could be significant to local airborne fungal spore composition and populations due to the relative large sizes of the basidiomata.

Basidiospores are one of the major components of airborne fungi in summer and fall in certain areas around the world (Tarlo *et al*. 1979, Vital & Krishnamoorthi 1988, Cosentino *et al*. 1990). Basidiospores were found to be the dominant airborne fungal spores in Hamilton, Ontario (Tarlo *et al*. 1979), and in Connecticut in the summer of 2004 (unpubl. data). However, studies on airborne basidiospores are scarce. Basidiospores in most studies were only identified as a group of basidiomycetes due to the difficulty in identifying basidiospores to genus and family levels based on morphological characters (Li & Kendrick 1995a, b, 1996). Very few studies have been conducted at the genus level for basidiospores. Airborne *Ganoderma*, *Coprinus*, *Agrocybe*, *Calvatia cyathiformis, Marasmius rotula* and *Chondrostereum purpureum* were the only few that were investigated (Dye 1974, Gilliam 1975, Tarlo *et al*. 1979, Levetin *et al*. 1992, Li & Kendrick, 1995a, Craig & Levetin 2000, Henríquez *et al*. 2001). Some studies were conducted at the species level on the release and dispersal of basidiomycetes

with a focus of basidiomata which included *Ganoderma applanatum* (Haard & Kramer 1970, Tarlo *et al*. 1979) *Marasmius rotula*, and *Chondrostereum purpureum* (Dye 1974, Gilliam 1975) and *Ganoderma lucidum* in India (Singh *et al*. 1995).

Some basidiospores are allergens (Santilli *et al*. 1985, Levetin *et al*. 1992, Horner *et al*. 1993). Sprenger *et al*. (1988) suggested that basidiospores could be important airborne allergens in the Pacific Northwest. It is necessary to study aerodynamics and temporal patterns of basidiomycetes so that such information can be applied to understanding human exposures and their effects on human allergies. It will be beneficial to study the release and dispersal of basidiospores from basidiomata at the genus and even species levels.

The objectives of the present study were to determine the temporal and spatial characteristics of release and dispersal of basidiospores of *Amanita muscaria* var. *alba* and to elucidate the potential of the basidiospores to infiltrate a nearby residence.

MATERIALS AND METHODS

Two fruit bodies of *Amanita muscaria* var. *alba* in a group developed simultaneously with the stalks touching each other at the base in late September 2004 on the edge of a mixed coniferous and deciduous wood behind a residential property in Avon, Connecticut. The residence, a two-story colonial single family building with walk-out basement and 7 m in height in the front and 10.2 m at the back was 6 m from the basidiomata. The predominant species of the mixed wood are Eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobes*), American chestnut (*Castanea dentata*), black birch (*Betula lenta*), northern red oak (*Quercus rubra*), white oak (*Q. alba*), and red maple (*Acer rubrum*). These trees are over 20 yr old and much taller than the residences in the neighborhood. The development of the fruit bodies was observed daily commencing from the time of expansion of the basidioma caps. When the fruit body commenced opening, 75×25 mm slides coated with a mixture of 90% petrolatum and 10% paraffin wax were put underneath one of the fruit bodies to catch some basidiospores for confirmation of identification. Once the fruit bodies were mature and their caps were fully expanded, air samplers were set up to take samples at 2 h intervals, 12 samples d^{-1}.

Three samplers, Allergenco MK-3 (Environmental Monitoring Systems, Mt Pleasant, SC) were used to take air samples. The Allergenco sampler collects multiple, discrete fungal spore deposits on 75×25 mm slides. Twelve samples per day were taken on a slide. All the samples were taken at 15 l min^{-1} for 10 min. One sampler was posited at ground level and 30 cm away from the two fruit bodies. It was placed on a metal pan to prevent water from soaking and damaging the sampler and to minimize the disturbance caused by outlet air to ground surface. A second sampler was placed at a height of 2.7 m off ground and 5.2 m away from the fruit bodies (second location) on a deck. The second sampler was 2.4 m away from the residence. The third sampler was placed in the living room of the residence. As the samplers are not waterproof, both samplers outdoors were sheltered by a cover of $62.5 \times 45 \times 60$ cm (Length × Width × Height) from rain damage. Samples were taken from 30 Sept. to 11 Oct. 2004. The slides used for sampling were replaced in the samplers at 18:30 h daily. Once slides were removed from the samplers, all spore deposits were marked with an extra fine sharpie marker at the lower ends of the deposits to allow locating the samples easily for analysis. The single longitudinal traverse method was used to read all 12 samples on a slide.

75×25 mm slides coated with a mixture of 90% petrolatum (Fisher, Pittsburgh, PA) and 10% paraffin wax (high melting point 54 °C) were used to collect samples (Li & Kendrick 1996).

After 7 Oct. *Trichoderma harzianum* and *Penicillium* spp. developed on the lower surfaces of the fruit bodies. The fruit bodies collapsed on 12 Oct., and were collected for laboratory examination. They were in too poor a condition to be preserved as vouchers.

Lacto-fuchsin mounting medium and 22×30 cover glasses were used to mount the samples. All the samples were analyzed under an Olympus BX 40 compound microscope equipped with phase contrast and DIC optics. The fungal spore identification was conducted at 400× or 1000×.

The sizes of basidiospores were measured by randomly choosing 30 basidiospores from samples collected on 30 Sept., 12 Oct., and prepared from gills of one of the basidiomata, respectively.

Weather data for Avon CT, provided by Rick Bunton, were collected in Avon with a Davis Vantage Pro Weather Station (Davis Instruments, Hayward, CA).

Data were analyzed with NCSS (NCSS, 329 North 1000 East, Kaysville, UT) for Pearson correlation analysis for multiple variables, one-way ANOVA and Tukey-Kramer Multiple-Comparison Test.

RESULTS

Observation of basidiomata development

Two basidiomata in a group started to develop on the ground at the edge of a mixed wood adjacent to a backyard covered by turfgrasses on 23 Sept. 2004. On 26 Sept., the basidiomata were white. Caps were above ground, spherical, and 5–6 cm diam, but not expanded. Separation of caps from volva commenced. The one on the north side was bigger than the one on the south side. On 29 Sept., the basidiomata were partially expanded. Very few basidiospores were released. The basidiomata were fully expanded on 30 Sept. However, the two basidiomata were too close to each other and their caps were forced downward and bent at the sides where the caps met. The basidiomata were similar in

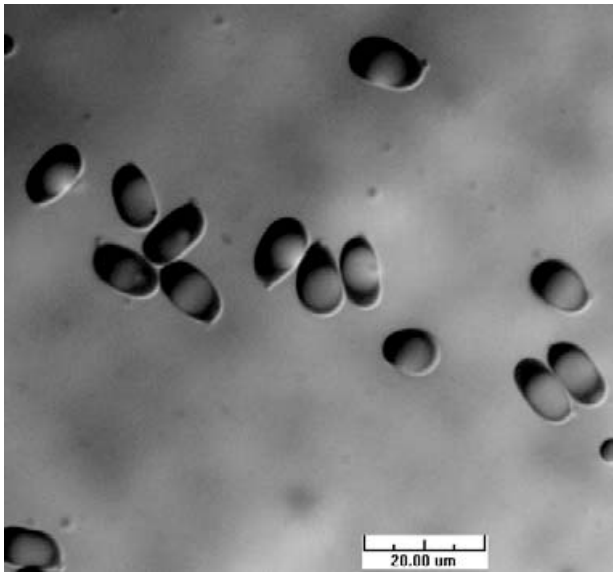

Fig. 1. Basidiospores of *Amanita muscaria* var. *alba* from an air sample.

sizes (13 cm tall, and 12 and 13.5 cm in cap diameter, respectively). On 8 Oct., basidiomata turned from a whitish to tan to light brown and started to shrink. At the same time, *Trichoderma harzianum* and *Penicillium* spp. were observed to develop on the underside surfaces of the caps. Eventually, *Trichoderma harzianum* and *Penicillium* spp. completely covered the underside surfaces of the caps. On 11 Oct., both basidiomata collapsed.

Basidiospores

The basidiospores were broadly ellipsoid to elongate, smooth, thin-walled, hyaline, guttulate, and with a conspicuous hilum (Fig. 1). However, the size of basidiospores at the early stage of spore release was 11–16 × 5.5–8.5 μm (12.5 ± 2.6 × 7 ± 1.4 μm), significantly longer than the spores released at late stage (8.5–13.5 × 5–8.5 μm (10.5 ± 2.2 × 7 ± 1.4)) according to Tukey-Kramer Multiple-Comparison Test ($p = 0.05$) (Table 1). The widths of the basidiospores did not show significant differences between the early and late stage of release. There was no significant difference in sizes of basidiospores collected at the early stage of full cap expansion and at the late stage (Table 1).

When basidiomata were partially expanded, very few spores were released. Once the basidiomata were fully expanded, within several hours, a large amount of spores were released into the air. The first three days were the peak period for the basidiomata to release basidiospores. The concentration of basidiospores near the basidiomata in the first day of full expansion of basidiomata was highest with an average of 77 137 spores m^{-3} and the concentration ranged from 21 992 to 151 270 spores m^{-3} (Figs 2–3). However, the highest concentration of 281 738 spores m^{-3} appeared around 2:00 am in the second day with a daily average of 75 062 spores m^{-3}. The average basidiospore concentration in the air in the third day dropped 44 % from the second day to 41 738 spores m^{-3} and the concentration ranged from 2261 to 204 838 spores m^{-3} (Fig. 3). The average concentration in the fourth day dropped 95 % from the third day to 1954 spores m^{-3}. After 4 d, the basidiospore concentrations were less than 400 spores m^{-3} (Figs 2–3).

Basidiospore release exhibited a diurnal pattern with night peaks according to the means of 10-observation days (Fig. 4). Basidiospores were released mainly during the night with a major peak of 55 562 spores m^{-3} at 02:00 and two minor peaks of 53 071 spores m^{-3} and 41 273 spores m^{-3} at 20.00 h and 06.00 h, respectively. The peak period lasted over 10 h. During the daytime, the concentrations were $<20\,000$ spores m^{-3} (Fig. 4). The diurnal patterns in the second and third days showed much shorter peak periods (Fig. 2).

Airborne basidiospore concentrations dropped by 96–99 % at the second location. Mean concentrations of basidiospores in the first three days were 940, 575, and 1359 spores m^{-3}, respectively (Figs 5–6). Concentrations of airborne basidiospores dropped to <250 spores m^{-3} three days later following the full expansion of basidiomata (Fig. 6). Airborne basidiospores at this location showed a diurnal pattern, but with a much longer peak period which lasted from

Table 1. Sizes of basidiospores of *Amanita muscaria* var. *alba* during release and dispersal.

Sampling date	*n*	Length (μm)	Breadth (μm)	L/B
30 Sept.	30	13.5 ± 0.23[a]a[b]	7 ± 0.13 a	2 ± 0.04 a
7 Oct.	30	10.5 ± 0.23 b	7 ± 0.13 a	1.5 ± 0.04 b
12 Oct.	30	10.5 ± 0.23 b	7 ± 0.13 a	1.5 ± 0.04 b

[a] data are mean ± SE.

[b] Data in the same columns with different letters indicate statistically significant differences according to Tukey-Kramer Multiple-Comparison Test ($P < 0.05$).

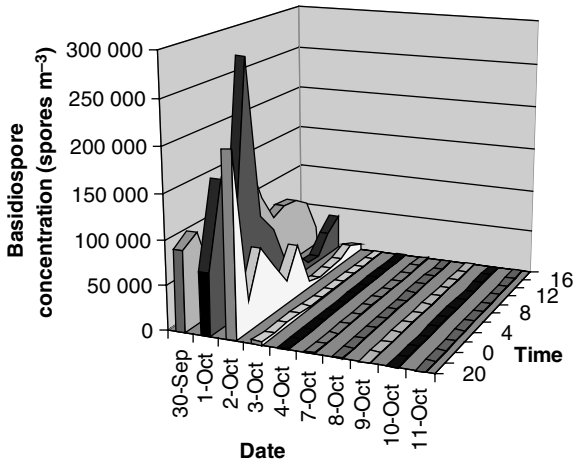

Fig. 2. Temporal patterns of basidiospores of *Amanita muscaria* var. *alba* released from basidiomata.

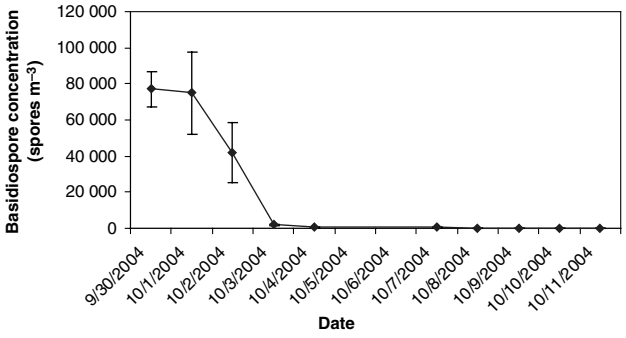

Fig. 3. Daily concentrations of basidiospores of *Amanita muscaria* var. *alba* released from basidiomata. The values are the means of 12-bihourly concentrations (± SE).

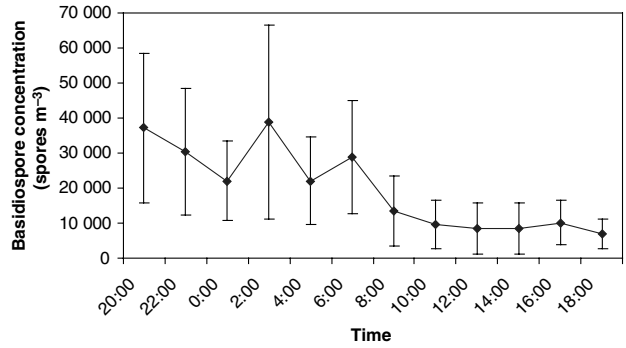

Fig. 4. Diurnal pattern of basidiospores of *Amanita muscaria* var. *alba* released from basidiomata. The values are the means of 10 days (± SE).

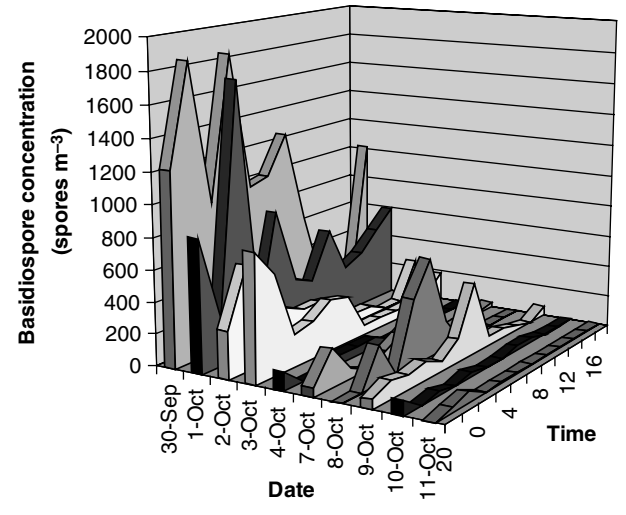

Fig. 5. Temporal patterns of basidiospores of *Amanita muscaria* var. *alba* dispersed to the second location.

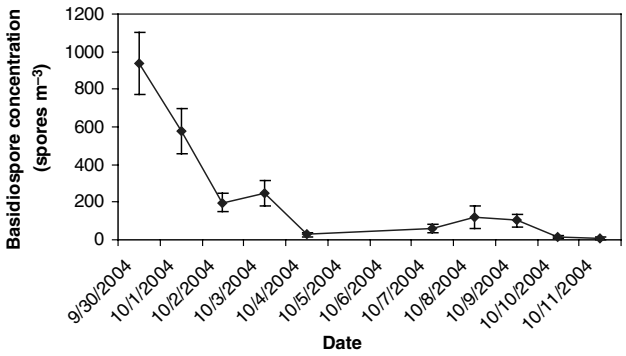

Fig. 6. Daily concentrations of basidiospores of *Amanita muscaria* var. *alba* dispersed to the second location. The values are the means of 12-bihourly concentrations.

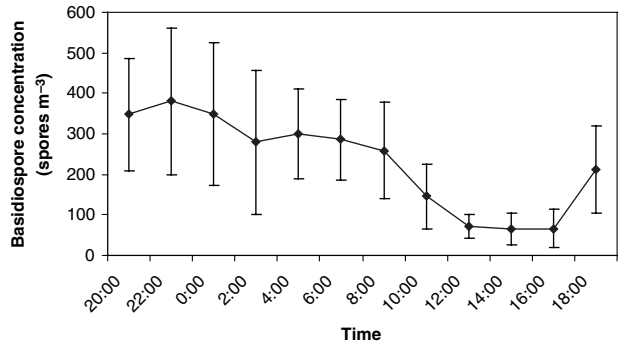

Fig. 7. Diurnal pattern of basidiospores of *Amanita muscaria* var. *alba* dispersed to the second location. The values are the means of 10 days (± SE).

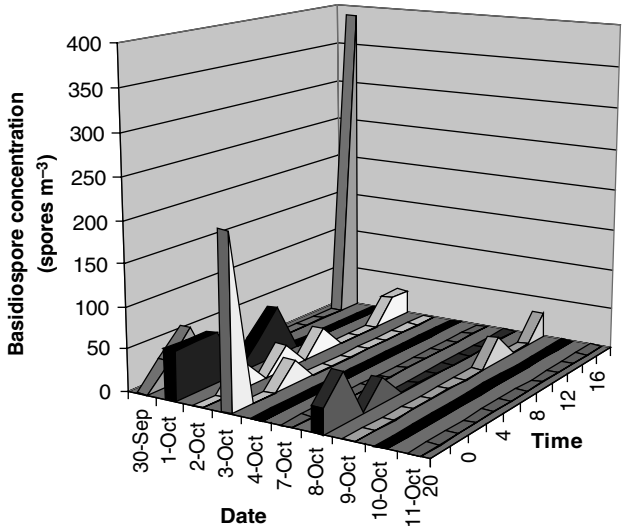

Fig. 8. Daily concentrations of basidiospores of *Amanita muscaria* var. *alba* dispersed into the residence.

18.00 h to 08.00 h (Fig. 7). Airborne basidiospore population was observed to plunge significantly after 10.00 h and reached the lowest level at 14.00 h (Fig. 7).

A very small number of basidiospores infiltrated the residence through open windows or doors from time to time everyday (Fig. 8). Airborne basidiospore concentrations in the first four days were 40, 22, 12, and 20 spores m^{-3}, respectively (Figs. 8–9). After four days, airborne basidiospores were usually absent in the living room, except for 8 and 9 Oct. The highest concentration was 387 spores m^{-3} at 18.00 h on 30 Sept. Airborne basidiospores in the living room showed a

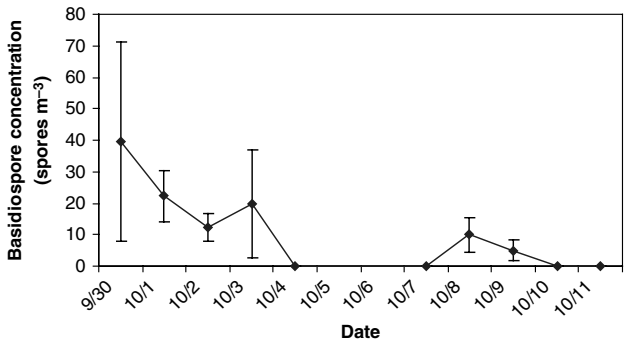

Fig. 9. Daily concentrations of basidiospores of *Amanita muscaria* var. *alba* dispersed into the residence. The values are the means of 12-bihourly concentrations.

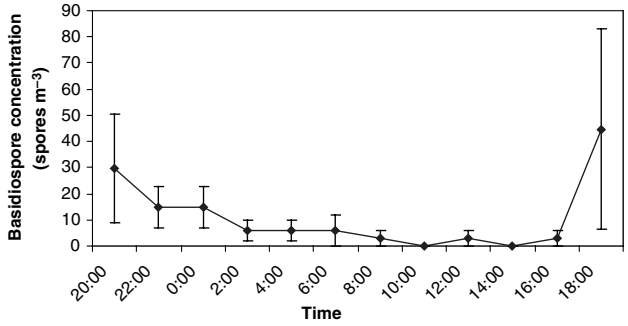

Fig. 10. Diurnal pattern of basidiospores of *Amanita muscaria* var. *alba* dispersed into the residence. The values are the means of 10 days (± SE).

diurnal pattern with a maximal period from 18.00 h to 20.00 h and a minimum during the daytime (Fig. 10).

According to Pearson Multiple Correlation Analysis, Airborne basidiospores on the deck (sampler 2) showed a significant correlation with those in the living room (Table 2). Basidiomata age was very strongly and negatively correlated with basidiospore release and short distant dispersal. Time of day was not significantly correlated with basidiospores indoors and outdoors. Keeping windows or doors open was positively correlated with concentration of basidiospores in the living room. However, resident activity did not correlate with basidiospores in the living room. Relative humidity (RH) and dew were positively correlated with basidiospore release and short distance dispersal, while rain (light showers) and rain rate were positively correlated with basidiospore release, but not with short distance dispersal (Table 2). RH, dew, and rain were not correlated with the basidiospores in the living room. Wind, including wind velocity, maximum wind velocity, wind direction and wind run was negatively correlated with basidiospore release and short distance dispersal. Barometric pressure was not significantly correlated with basidiospore release, and short distance dispersal (Table 2). Temperatures (maximum, average, minimum), heat index, heat DD, and THW (Temperature Humidity Wind Index) were not correlated with either basidiospore release or short distant dispersal (Table 2).

DISCUSSION

Philips (1991) stated that *A. muscaria* var. *alba* developed basidiomata from August to September. However, during the present study, they formed in October in Connecticut. Fully expanded basidiomata of *A. muscaria* var. *alba* lasted over 10 days, but the basidiomata released most basidiospores in the first three days following full expansion. Haard & Kramer (1970) observed that *Inocybe fastigiata* and *Mycena rudilanthiformis* (?*M. roriduliformis*) released their basidiospores mainly in the first 24–48 h after the pileus of the basidiomata were fully expanded. Other agarics and boletes discharged their basidiospore continuously for 1–6 days (Gilliam 1975).

The basidiospores released in the first three days following the full expansion of basidiomata were significantly longer than the ones released several days later and the ones still on gills. Change in length of basidiospores could be in part due to availability of nutrients and water for basidiospore development. One week after the basidiomata's maturation, the basidiomata commenced to shrink and discolour. The deterioration was obvious. Metabolism at this stage in the basidiomata might not be able to provide quality nutrients and enough water for the development of basidiospores. However, more studies are necessary to determine the reasons and mechanism of change in length of basidiospores at different stages of basidioma development. Phillips (1991) described basidiospores that were '7.9–14.1 × 6.3–9.4 μm,' shorter and wider than the ones observed (11–16 × 5.5–8.5 μm) in this study. Arora (1986) indicated the size of spores of *Amanita muscaria* was 9–13 × 6.5–9 μm, however, he did not provide the spore sizes of different varieties. However, in their recent monograph Neville & Poumarat (2004) give the spores of var. *alba* as '(7.7) 9–11(–13) × (6.3)7.7–8.3(9) μm'. These observations were in general agreement with the observation of the spores released at the late stage, 8.5–13.5 × 5–8.5 μm in this study, although slightly wider. The differences could be due to variations in fungal populations and geographic distribution.

Based on the literature, there was no indication of the presence of guttules in basidiospores as observed in this study. The presence of guttules could reduce the density of basidiospore and could be beneficial for basidiospore release and dispersal. Guttules could also serve as stored energy source for basidiospores' survival. However, future studies are necessary to understand the role of guttules in the life-cycle of *A. muscaria* var. *alba*.

Amanita muscaria var. *alba* released most of its basidiospores in the first three days following the full

Table 2. Pearson Correlations Analysis of environmental factors and airborne basidiospore populations of *Amanita muscaria* var. *alba* at three locations.

	By basidiomata		On deck		In living room	
Factor	*r*	*p*	*r*	*p*	*r*	*p*
By basidiomata	1.00	0.000*	0.50	0.000*	0.09	0.328
On deck	0.50	0.000*	1.00	0.000*	0.33	0.000*
In living room	0.09	0.328	0.33	0.000*	1.00	0.000*
Basidioma age	−0.56	0.000*	−0.59	0.000*	−0.24	0.007*
Time	−0.04	0.68	−0.04	0.626	0.13	0.145
Open window/door	X[a]	X	X	X	0.18	0.044*
Resident activity	−0.09	0.348	−0.08	0.361	0.16	0.074
Barometric pressure	0.18	0.054	0.16	0.089	0.10	0.263
Dew	0.28	0.002*	0.31	0.000*	0.15	0.094
Heat D D	−0.03	0.738	0.02	0.811	−0.14	0.141
Heat index	0.04	0.645	−0.00	0.926	0.13	0.165
Rain	0.40	0.000*	0.00	0.922	−0.03	0.727
Rain rate	0.39	0.000*	0.01	0.863	−0.02	0.788
Relative humidity	0.33	0.000*	0.44	0.000*	0.03	0.731
Temperature-max	0.01	0.893	−0.04	0.628	0.12	0.191
Temperature-mean	0.01	0.895	−0.05	0.623	0.12	0.200
Temperature-min	0.02	0.857	−0.04	0.676	0.12	0.183
THW	0.04	0.613	−0.00	0.977	0.13	0.159
Wind velocity	−0.29	0.001*	−0.38	0.000*	−0.19	0.035*
Wind velocity-max	−0.32	0.000*	−0.43	0.000*	−0.22	0.018*
Wind direction	−0.19	0.038*	−0.34	0.000*	−0.34	0.000*
Wind run	−0.29	0.001*	−0.38	0.000*	−0.19	0.035*

* *p* is significant.
[a] X, correlation not biologically meaningful.

expansion of basidiomata. During this period, a very large number of basidiospores were released into the air. The highest concentration of basidiospores near the basidiomata reached 281 738 spores m^{-3}. Gregory *et al.* (1953) observed a similar result with *Serpula lacrymans*, where basidiospore concentrations near basidiomata reached up to 3.6×10^5 spore m^{-3}. In the present study the number of basidiospores released on the fourth day dropped by 95%. This explained why basidioma age was negatively correlated with basidiospores outdoors after the caps of the basidiomata were fully expended. The period of basidiospore release of *A. muscaria* var. *alba* was short and concentrated. Rockett & Kramer (1974) reported that annual lignicolous polypores released large numbers of basidiospores in a single short period, while *Trametes versicolor* and other leathery annual polypores discharged smaller numbers of basidiospore over a much longer period.

Basidiospore release of *A. muscaria* var. *alba* showed a diurnal pattern with a maximum release period at night. However, the pattern was not well defined and peak periods at nights in the first three days varied due to the influence of RH and rain. Part of the reason may have been due to rains and high relative humidity during the release period. There were light showers in the afternoon of 30 Sept., in the morning of 1 Oct., and in the evening of 2 Oct., respectively. Relative humidity was very high ranging from 95 to 100% at night and in part of the morning on both 30 Sept., and 1 Oct. 2004. Rain and relative humidity were important factors for basidiospore release. The effect of rain on airborne fungal spores depends on its intensity and duration (Lacey 1996). The reason for no correlation between rain and airborne basidiospores at the second sample site may be due, in part, to light showers not affecting short distance dispersal significantly. A number of basidiomycetes, such as *Coprinus* and *Ganoderma*, showed well defined diurnal patterns with a maximum period at night (Li & Kendrick 1995b, Craig & Levetin 2000). Haard & Kramer (1970) found *Crepidotus*, *Panaeolus*, and *Oudemansiella* showed a diurnal pattern with a maximum period around midnight and a minimum during the daytime. However, Kramer & Long (1970) found that under laboratory conditions (21 ° and RH 90%) *Ganoderma applanatum* showed an endogenous rhythm of spore release with maxima occurring at 9–10 h intervals under either alternating 12 h light-dark or continuous light. Gilliam (1975) found that the discharge of basidiospores of *Marasmius rotula* was rain-dependent and did not follow the diurnal patterns displayed by other agarics. These results indicated that the release of basidiospores might be influenced by RH and rain or controlled by an endogenous biological mechanism. The lack of a significant correlation between time and airborne basidiospores outdoors may indicate that the diurnal patterns observed in the present study were not well established or defined. It may not be endogenous as showed by *Ganoderma applanatum*. Further studies are necessary to determine the exact mechanism of controlling basidiospore release and temporal pattern of *A. muscaria* var. *alba*.

Negative correlations between wind speed and basidiospore concentration by the basidiomata and the location which was 5.2 m away and 2.7 m off ground might be due, in part, to the collection efficiencies of the samplers, which might be reduced when wind speed reached certain levels. The lack of correlation between wind direction and basidiospore release was mainly due to basidiomata development at a location where three sides were surrounded by woods; only the east side was open and faced a residential lawn. At the same time, ground cover plants could interfere with air movement on the surface of the ground. However, air could move freely around the sampler which was 5.2 m away from the basidiomata. The negative correlation might be due to the local turbulence caused by the rail around the deck. As a result, the collection efficiency of the sampler may be reduced.

The concentrations of airborne basidiospores at the second location dropped 98%. The results indicated that 98% of basidiospores settled within an area with a 5.2 m radius and fewer than 2% of basidiospores dispersed to areas beyond 5.2 m from the basidiomata and 2.7 m above them. Philip H. Gregory and Margaret F. Gregory predicted that 90% of fungal spores from sources near the ground would deposit within 100 m in normal turbulence (Lacey 1996). The dispersal distance of the basidiospores of *A. muscaria* var. *alba* was much shorter in the present study. Part of the reason may be that the spore dispersal process is complex. Not all spores will travel the same distance due to wind turbulence or irregular air movement (Lacey 1996). McCartney (1991) indicated that the spore dispersal process is determined by wind speed, turbulence, and spore size. The size (relative large) and shape (broadly ellipsoid to elongate) of basidiospores of *A. muscaria* var. *alba* may be the two major factors in their rapid deposition. Low wind speeds and lack of eddy near the ground could be another reason also. However, further studies on spore dispersal of this fungus are necessary.

Airborne fungal spores can cause not only allergenic reactions, but also infections and mycotoxicosis to human beings and animals (Lacey 1996). It is clear that basidiomata of *A. muscaria* var. *alba* can release a large number of basidiospores into the air at its peak period. However, it is not fully understood when mushroom hunters or individuals within the close proximity of basidiomata are exposed to such a high concentration, what kind of health effects these basidiospores may have, especially for the species which are toxigenic. Also, it will be useful to determine how many basidiospores can be developed in a basidioma in future studies.

As the caps of the basidiomata were not completely expanded and part of caps bent downward, release and dispersal of basidiospores from these parts of caps might be significantly reduced.

Only a very small number of basidiospores ($<0.001\%$) released from the basidiomata were recovered inside the residence living room, even in close proximity to the basidiomata and with open windows or doors from time to time. This indicates that *A. muscaria* var. *alba* has a low dispersal ability and its ability to infiltrate a residency is relatively low. The reason for the lack of correlation between resident activity and airborne basidiospores was due to, in part, the relatively large size of the basidiospores. Routine resident activity may not be efficient enough to re-suspend settled basidiospores into the air. The filter in the HVAC system in the house may play a significant part by efficiently removing a large amount of basidiospores infiltrating the residence from the indoor air. Further studies on fungal infiltration of residences and other buildings are necessary to determine the interactive effects with architecture, building materials, HVAC systems, and maintenance and subsequently to determine the functional relationships of airborne fungi indoors and outdoors. Information from such research is imperative for the professionals who are conducting indoor air quality and indoor fungi investigation and remediation.

The rain shields used to protect the samplers might have effects on the collection of basidiospores. Rain might affect both basidiospore release and dispersal. Rain falling on the caps would generate minute vibrations, which might directly affect the release of basidiospores. Rain could wash out airborne basidiospores from the air and reduce the dispersal distance of this fungus. At the same time, the rain shield might significantly change the aerodynamics of air movement around the samplers. Such a change might have a significant effect on spore collection efficiency. Thus, it will be necessary to study the effects of rain shield on spore collection. It will be beneficial if the manufacturer can develop a water proof model for aeromycological research.

ACKNOWLEDGMENT

I am indebted to Rick Bunton for providing Avon weather data and to Louis Magnarelli and James LaMondia for their review of the manuscript.

REFERENCES

Arora, D. (1986) *Mushrooms Demystified*. 2nd edn. Ten Speed Press, Berkeley.

Chilton, W. S. & Ott, J. (1976) Toxic metabolites of *Amanita pantherina*, *A. cothurnata*, *A. muscaria* and other *Amanita* species. *Lloydia* **39**: 150–157.

Cosentino, S., Pisano, P. L., Fadda, M. E. & Palmas, F. (1990) Pollen and mould allergy: aerobiologic survey in the atmosphere of Cagliari, Italy (1986–1988). *Annals of Allergy* **65**: 393–399.

Craig, R. L. & Levetin, E. (2000) Multi-year study of *Ganoderma* aerobiology. *Aerobiologia* **16**: 75–81.

Dye, M. H. (1974) Basidiocarp development and spore release by *Stereum purpureum* in the field. *New Zealand Journal Agricultural Research* **17**: 93–100.

Gilliam, M. S. (1975) Periodicity of spore release in *Marasmius rotula*. *Michigan Botanist* **14**: 83–90.

Gregory, P. H., Hirst, J. M. & Last, F. T. (1953) Concentrations of basidiospores of the dry rot fungus (*Merulius lacrymans*) in the air of buildings. *Acta Allergologica* **6**: 168–174.

Haard, R. T. & Kramer, C. I. (1970) Periodicity of spore discharge in the *Hymenomycetes*. *Mycologia* **62**: 1145–1169.

Henríquez, V. I., Villegas, G. R. & Nolla, J. M. R. (2001) Airborne fungi monitoring in Santiago, Chile. *Aerobiologia* **17**: 137–142.

Horner, W. E., Levetin, E. & Lehrer, S. B. (1993) Basidiospore allergen release: elution from intact spores. *Journal of Allergy and Clinical Immunology* **92**: 306–312.

Kramer, C. L. & Long, D. L. (1970) An endogenous rhythm of spore discharge in *Ganoderma applanatum*. *Mycologia* **62**: 1138–1144.

Lacey, J. (1996) Spore dispersal – its role in ecology and disease: the British contribution to fungal aerobiology. *Mycological Research* **100**: 641–660.

Levetin, E., Horner, W. E. & Lehrer, S. B. (1992) Morphology and allergenic properties of spores from four *Calvatia* species. *Mycologia*. **84**: 759–767.

Li, D. W. & Kendrick, B. (1995a) A year-round comparison of fungal spores in indoor and outdoor air. *Mycologia* **87**: 190–195.

Li, D. W. & Kendrick, B. (1995b) A year-round outdoor aeromycological study in Waterloo, Ontario, Canada. *Grana* **34**: 199–207.

Li, D. W. & Kendrick, B. (1996) Functional and causal relationships between indoor and outdoor airborne fungi. *Canadian Journal of Botany* **74**: 194–209.

Lindgren, J. (1998) Trial key to the species of *Amanita* in the Pacific Northwest. http://www.svims.ca/council/Amanit.htm.

McCartney, H. A. (1991) Airborne dissemination of plant pathogens. *Society of Applied Bacteriology Symposium Supplement* **70**: 39S–48S.

McCracken, F. I. (1987) Factors affecting the spore release of *Ganoderma applanatum*. *Journal of the Mississippi Academy of Sciences* **32**: 55–60.

Michelot, D. & Melendez-Howell, L. M. (2003) *Amanita muscaria*: chemistry, biology, toxicology and ethnomycology. *Mycological Research* **107**: 131–146.

Mohan, V., Natarajan, K. & Ingleby, K. (1995) Anatomical studies on ectomycorrhizas II. The ectomycorrhizas produced by *Amanita muscaria*, *Laccaria laccata* and *Suillus brevipes* on *Pinus patula*. *Mycorrhiza* **3**: 43–49.

Nehls, U., Bock, A., Einig, W. & Hampp, R. (2001) Excretion of two proteases by ectomycorrhizal fungus *Amanita muscaria*. *Plant, Cell and Environment* **24**: 741–747.

Neville, P. & Poumarat, S. (2004) *Amaniteae: Amanita, Limacella & Torrendia*. [Fungi Europaei No. 9.] Edizion: Candusso, Alassio.

Philips, R. (1991) *Mushrooms of North America*. Little Brown, Boston, MA.

Rochett, T. R. & Kramer, C. L. (1974) Periodicity and total spore production by lignicolous basidiomycetes. *Mycologia* **66**: 817–829.

Santilli jr, J., Rockwell, W. J. & Collins, R. P. (1985) The significance of the spores of the basidiomycetes (mushrooms and their allies) in bronchial asthma and allergic rhinitis. *Annals of Allergy* **55**: 469–471.

Singh, A. B., Gupta, S. K., Pereira, B. M. & Prakash, D. (1995) Sensitization to *Ganoderma lucidum* in patients with respiratory allergy in India. *Clinical Experiment Allergy* **25**: 440–447.

Sprenger, J. D., Altman, L. C., O'Neil, C. E., Ayars, G. H., Butcher, B. T. & Lehrer, S. B. (1988) Prevalence of basidiospore allergy in the Pacific Northwest. *Journal of Allergy and Clinical Immunology* **82**: 1076–1080.

Tarlo, S. M., Bell, B., Srinizasan, J., Dolovich, J. & Hargreave, F. E. (1979) Human sensitization to *Ganoderma* antigen. *Journal of Allergy and Clinical Immunology* **64**: 43–49.

Tupalska-Wilczynska, K., Ignatowicz, R., Poziemski, A., Wojcik, H. & Wilczynski, G. (1997) *Amanita pantherina* and *Amanita muscaria* poisonings–pathogenesis, symptoms and treatment. *Polski Merkuriusz Lekarski* **3**: 30–32.

Vittal, B. P. R. & Krishnamoorthi, K. (1988) A census of airborne mould spores in the atmosphere of the city of Madras, India. *Annals of Allergy* **60**: 99–101.

Corresponding Editor: N. P. Money