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REVIEW ARTICLE

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House dust mites and their sensitivity to wood oils and volatiles

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Abstract Allergic diseases such as bronchial asthma, perennial rhinitis, and atopic dermatitis caused by the house dust mites *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae*, which are dominant species in homes, have recently become serious health problems. Reducing the number of and exposure to mites and mite allergens are the most important factors in preventing allergic diseases. Recently, the effects of essential oils of plants on house dust mites have received much attention with a view to producing natural mite-killing agents. Essential oils and their components of wood and their leaves have also received much attention. In this article, we summarize the biology of house dust mites, mite allergens, and their concentration in homes, and discuss the control of house dust mites by using plant and wood extractives, especially in relation to the influence of essential oils and volatiles from wood on house dust mites.

Key words House dust mite · *Dermatophagoides pteronyssinus* · *Dermatophagoides farinae* · Essential oil · Wood volatiles

Introduction

Around 30% of the Japanese population suffers from allergic diseases, such as bronchial asthma, perennial rhinitis, and atopic dermatitis, and these have become serious health problems in recent years.[1] Asthma is of particular concern because it is a potentially fatal disease.[2,3,4] In Japan, 4%–6% of children and 3%–4% of adults, or about 4 million people in total, show symptoms of asthma.[1] In 2000, the World Health Organization reported that around the globe between 100 and 150 million people suffer from asthma and this number is rising, and deaths from this condition exceed 180000 annually.[3]

Indoor environmental pollutants are closely related to these allergic diseases. One of the most important producers of the allergens for these diseases are the house dust mites *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae*, which are the dominant species in homes.[5,6,7]

Evaluations of serum-specific IgE antibody (sIgE ab) tests and skin tests showed that the allergen most frequently sensitized was house dust mite.[8–11] Measurements of sIgE ab in the sera from 587 junior high school students with and without allergic diseases indicated that 48.9% of them had sIgE ab to house dust mite allergens.[8] In the sera from 398 adults with bronchial asthma and from 364 adults with atopic dermatitis, sIgE ab to house dust mite allergens was also measured, and 242 of the 398 (60.8%) asthma sufferers and 301 of the 364 (82.7%) with atopic dermatitis showed positive results.[9,10] Skin tests of 1912 outpatients treated in allergy clinics showed that about 40% of them had sIgE ab to house dust mite allergens.[11]

The first requirement for achieving environmental control of the indoor environment is to identify and remove the source of the pollutants.[12,13] This means the number of live mites, the amount of mite feces and mite corpses, and the exposure to mites must all be reduced in order to prevent allergic diseases caused by house dust mites. It is known that housework, for example regular cleaning of rooms and upholstered furniture, and washing bedding and clothing is effective in reducing the number of mites and mite allergens.[4,14–21] However, such preventive measures require a great amount of time and effort, and a combination of several methods is required to control house dust mites and improve indoor environments.

Keeping the relative humidity low is another effective way of controlling house dust mites,[22–34] as is the use of

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acaricides. In recent years, the use of oils and extractives of plants and wood on house dust mites as a possible way of killing mites has received much attention from the viewpoint of the effective utilization of such plants and wood.[35–61]

In this article, we summarize the life cycle of house dust mites, the house dust mite allergen concentrations in homes, and means of controlling house dust mites using plant and wood extractives, especially essential oils and volatiles from wood.

Life cycle of house dust mites

The house dust mites *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae* are arthropods belonging to the phylum Arthropoda, class Arachinida, order Acari, and family Pyroglyphidae. The class Arachinida consists of spiders, scorpions, and similar organisms that are not closely related to insects. They have eight legs and are oval-shaped, and there is no clear boundary between their cephalothoraxes and abdomens. The length of the adult mites of *D. pteronyssinus* and *D. farinae* is 0.3–0.4 mm. The life cycle of these two mite species is made up of five stages: egg, larva, protonymph, tritonymph, and adult.[62]

The optimum development conditions for *D. pteronyssinus* and *D. farinae* have been found to be 20°–25°C, 65%–85% relative humidity (RH),[22–24,26–29] 25°C under 75%–76% RH,[22,23] and 25°C under 60%–76% RH,[23,24] from studies on mass culture and individual rearing. Under these conditions, the development times from egg to adult of *D. pteronyssinus* and *D. farinae* are about 30–40 days and 30–45 days, respectively, and the longevity of mating adults of these species is about 1–4 months and 2–3 months, respectively.[23] Two or three eggs are produced per day per female for *D. pteronyssinus* while *D. farinae* females produce one or two eggs per day. The total numbers of eggs produced per female during the reproduction period are 40 to 100 for *D. pteronyssinus* and 50 to 80 for *D. farinae*.[23]

The development of *D. pteronyssinus* and *D. farinae* is greatly influenced by temperature.[63,64] Arlian et al.[63] and Arlian and Dippold[64] showed that the duration of the life cycle of these species varied inversely with temperature, for temperatures of 16°, 25°, 30°, and 35°C. At 16°C, the eggs of *D. pteronyssinus* and *D. farinae* developed to adults in a period of 122.8 days (*D. pteronyssinus*) and 140.1 days (*D. farinae*). In contrast, at 35°C, the developmental times for the species were 15.0 and 22.1 days, respectively.

The percentage of the mites that developed from eggs to adults was also influenced by temperature. Only 15% of *D. farinae* eggs became adult mites at 16°C, and the figure was only 2% at 35°C. In contrast, 59% of *D. pteronyssinus* eggs developed completely at 16°C and the figure was 87% at 35°C. From these results, Arlian and Dippold[64] showed that the temperature range for optimum development of *D. farinae* was much narrower than the range for *D. pteronyssinus*. For *D. farinae*, Waki and Matsumoto[24] observed almost no growth in the mite population in media kept at 20° and 35°C, a result similar to that of Arlian and Wharton.[65]

The development of *D. pteronyssinus* and *D. farinae* is also greatly influenced by relative humidity.[23,25–29,65,66] The mites are 70%–75% water by weight, and they obtain water and maintain their water balance primarily by absorbing water vapor from the air.[65,66] Matsumoto et al.[23] showed that the periods in the life cycles of *D. pteronyssinus* and *D. farinae* varied with relative humidity, using measurements at 61%, 76%, and 86% RH. *Dermatophagoides pteronyssinus* had its shortest development time, 37.1 days, at 76% RH, and the development times were 44.4 days at 61% RH and 41.1 days at 86% RH, a little longer than the figure for 76% RH. *Dermatophagoides farinae* had its shortest development time, 39.6 days, at 76% RH; other development times were 70.7 days at 61% RH, and 50.9 days at 86% RH, much longer than the figure at 76% RH. At 36% RH, all of the *D. pteronyssinus* and *D. farinae* mites died before the protonymphal stage.

Studies on mass culture of the mites have reported that almost no population growth was observed at 20%–61% RH (*D. pteronysissinus*) and 20%–55% RH (*D. farinae*).[22,25–29] *Dermatophagoides pteronyssinus* was more susceptible to desiccation than *D. farinae*.[23,26–29]

House dust mite allergen concentrations in homes and their seasonal variation

Many species of mites live in houses, but *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae* are the dominant species, constituting over 70% or so of the total mite population.[67–86] House dust mites feed principally on human skin scales and other organic detritus.[87,88] This means they thrive in flooring, bedding, mattresses, and sofas,[72–77,89–91] because these are areas where humans stay for a long time. Thus, the mite allergen content is high in these areas.[84,92–100]

In Japanese houses, there is a high mite population density in flooring, especially in carpets and tatami mats.[72–74,89,90,101] Studies on mite population densities in homes have shown that the numbers of mites is 193–3098 m^{-2} for carpets and 18–171 m^{-2} for tatami mats, but only 3–48 m^{-2} for wooden flooring.[74,75,77,89,90,101] The surface of wooden flooring is flat and easy to clean, and the wood is dry, making it unsuitable as mite habitat. These physical properties of wood help to suppress the number of mites and mite allergens on wooden flooring. It was reported that the number of mites on a floor decreased sharply when the flooring material was changed from carpet or tatami matting to wood, and the number of mites on sofas and beds also decreased.[102]

The number of house dust mites in homes varies seasonally in the temperate seasonal climates of Japan, North America, and Europe.[68,69,71,73,76,78,91–93,103–108] Usually, mites are found at their highest density in the humid summer season and early autumn. The density of mites drops in late autumn, and mites are found at the lowest densities in winter. These seasonal variations in the number of mites correlates with the seasonal changes in outdoor and indoor temperatures and relative humidity.[73,91–93,103,105,107,108]

In a survey of households with asthmatic children who were allergic to house dust mites, a strong correlation was observed between the seasonal variations of the mite population, which was highest in the summer and lowest in the winter, and the frequency of asthma attacks.[71] The increase in the number of mites encouraged by the rise in temperature and humidity greatly influenced the children's sensitivity and the acuteness of asthma attacks.

Mite allergens

Allergic diseases such as asthma, perennial rhinitis, and atopic dermatitis, which have recently become serious health problems, are caused by the dust mites *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae* in household dust.[5,6] Their bodies and feces are the sources of many allergens.[109] The bodies and feces of mites dry and become airborne particles, that can be inhaled into the bronchial tubes, or absorbed through injuries in the skin, causing an allergic reaction.[110] Ten groups of allergens from the house dust mite *Dermatophagoides* spp. are listed in the WHO/IUIS nomenclature.[7] The group 1 allergens Der p 1 from *D. pteronyssinus* and Der f 1 from *D. farinae*, which originate from mite feces, and the group 2 allergens Der p 2 and Der f 2, which originate from mite bodies, are considered to be major allergens.[7,111]

The levels of mites and mite allergens in houses are closely related to sensitization to asthma and its exacerbation. It is proposed that a level of 2 μg of group 1 allergens per gram of dust (equivalent to 100 mites per gram of dust) should be regarded as a risk factor for the sensitization and development of asthma. A level exceeding 10 μg of group 1 allergens per gram of dust (500 mites per gram of dust) may pose an especially high risk for the development of acute asthma in individuals allergic to mites.[7,111]

Controlling house dust mites

Generally, extermination of pests by pesticide requires much labor, time, and money. Moreover, it has caused problems for human health, and some pests have developed resistance to pesticides. Therefore, integrated pest management that keeps pest levels low enough to be harmless is required to minimize pesticide use.[112] A similar approach is also necessary for controlling house dust mites. House dust mites and their allergens cannot be avoided completely, and so it is important to decrease the number of mites and mite allergens to a low level where there is no health hazard. This can be done by improving indoor environments using various methods that complement the effects of housework such as cleaning and washing bedding and upholstery.

Housework

Eliminating contact with mites and mite allergens is important for controlling the allergic diseases caused by house dust mites. The following specific suggestions have been offered: (1) vacuum cleaning floors (carpets, tatami mats, and wooden floors) and upholstered furniture daily; (2) minimal use of carpets; (3) washing, drying, and dry cleaning bedding materials; and (4) using covers.[4,15–21]

Given the seasonal variation of mite populations, it would appear that in temperate climates, late winter and early spring are the best times of the year to thoroughly clean floors and beddings to kill mites that have survived the winter. This should reduce the chances of having a large infestation during the summer months. However, regular vacuuming and washing of bedding to control house dust mites requires much effort and time.

Effects of reducing relative humidity on house dust mites

Population densities of *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae* sharply increased when cultured at 20°–25°C and 65%–85% RH,[22–24,26–29] but decreased when cultured at 20°–25°C and 20%–61% RH (*D. pteronyssinus*) and 20%–52% RH (*D. farinae*).[22–29] Oribe and Miyazaki[26] cultured *D. pteronyssinus* at 23°C with RH levels of 85%, 75%, 61%, 51%, and 33%, and showed that their populations at 85% and 75% RH grew exponentially, increasing by factors of 10 and 8.4, respectively. On the other hand, with RH levels of 61%, 51%, and 33%, their populations decreased to 68%, 49%, and 35% after 14 days, and to 22%, 20%, and 8% after 21 days, respectively, and no moving mites were observed after 35 days. These results show that both *D. pteronyssinus* and *D. farinae* were susceptible to desiccation; therefore, reducing the relative humidity indoors to less than 52% appears to be an effective way of controlling these mites in homes.

On the other hand, laboratory studies have shown that *D. pteronyssinus* and *D. farinae* have high reproductive potential and high population growth rates,[30] and that *D. farinae* can complete development given only short periods of moist air every day. This indicates that even in conditions with low relative humidity, mite densities can quickly return to high levels after a recovery in conditions where adequate food and suitable microclimatic conditions exist.[31,32] However, under dry conditions, the number of eggs produced was approximately one third of the number produced at a constant RH of 75%.[30] The rate of development of mites was also much slower than the rate of development at a constant RH of 75%.[31] This indicates that reducing the ambient relative humidity and keeping it below 52% for long periods is effective in restricting the population growth of mites and thus the production of allergens.

Several studies have demonstrated the effect of reducing the relative humidity indoors on controlling mites in homes.[33,34] In homes where high-efficiency dehumidifiers and air conditioners were used and the relative humidity was kept to less than 51% for 17 months, allergen levels were more than 10 times lower than in homes where the climate was controlled by opening windows, and which had a relative humidity of more than 51%.[33] Houses equipped with 24-h ventilation and air-conditioning systems were found to have a low relative humidity, 63%–66% in the period from July to September, and 10% fewer house dust mite allergens compared with houses without ventilation and air-conditioning systems, which were at 73%–77% RH in the period from July to September.[34] These studies showed that it is practical to maintain a relative humidity indoors of less than 51% or 63%–66% during the humid summer season in temperate climates, and that this can help to reduce mite and allergen levels.

On the other hand, excessively dry conditions may cause dryness in the skin and inflammation of the nose and the pharynx mucous membrane.[113] Therefore, further research is necessary to show the possibility and means for providing a suitable humidity environment that controls house dust mites at the same time as remaining comfortable for humans.

Effects of plant and wood oils on house dust mites

Usually, acaricides are used to kill mites, but in recent years the use of the essential oils of plants as a possible way of killing house dust mites has received much attention from the viewpoint of the effective utilization of such plants.[35–44] Watanabe et al.[35] examined the abilities of 82 kinds of essential oils to kill the mites *D. pteronyssinus* and *D. farinae*. They found that 52 kinds of essential oils had the ability to kill mites, especially almond bitter (*Prunus amygdalus* var. *amara*) oil, caraway (*Carum carvi*) oil, dill (*Anethum graveolens*) oil, spearmint (*Mentha spicata*) oil, houshou (*Cinnamomum camphora* var. *glaucescens*) oil, and wintergreen (*Gaultheria procumbens*) oil, and that benzaldehyde, D-carvone, L-carvone, linalool, and methyl salicyate, which were the main components of these essential oils, were also very effective.

Ottoboni et al.[36] evaluated ten essential oils and found that the ones that were most effective for exterminating *D. pteronyssinus* were caraway, garlic (*Allium sativum*), black pepper (*Piper nigrum*), and Peru balsam (*Myroxylon pereirae*). Extracts of *Uvaria pauci-ovulata* bark,[37] senkyu (*Cnidium officinale*) rhizome,[38] clove (*Eugenia caryophyllata*) bud oil,[39] *Uvaria versicolor* stems,[40] tonka (*Dipterix odorata*) bean,[41] anise (*Pimpinella anisum*) seed,[42] fennel (*Foeniculum vulgare*) fruit,[43] and peony (*Paeonia suffruticosa*) root bark[44] had particularly strong acaricidal properties, killing both *D. pteronyssinus* and *D. farinae*. Analysis of their components showed that benzyl benzoate,[37,40] squamocin,[37] butylidenephthalide,[38] eugenol and its congeners, and especially methyleugenol,[39] coumarin,[41] *p*-anisaldehyde,[42,43] (+)-fenchone,[43] paenol, and benzoic acid,[44] which were contained in their extracts, had strong acaricidal effects.

Effects of leaf oils on house dust mites

The essential oils of tree leaves have also received much attention. Miyazaki et al.[45] summarized the effects of 27 leaf oils from various genera on the activity of *D. pteronyssinus*. Leaf oils from the genus *Thuja* and the genus *Eucalyptus* had strong effects on mites, while the effects of *Picea*, *Abies*, *Thujopsis*, and *Juniperus* oils on mites were moderate. *Pinus* and *Chamaecyparis* oils had slightly more effect on the mites than the oils of other genera used in the experiment. The leaf oils of hinoki-asunaro (*Thujopsis dolabrata* var. *hondai*),[46] wintergreen,[35] tabunoki (*Machilus thunbergii*),[47] urajiromomi (*Abies homolepis*),[47] *Eucalyptus citriodora*, Norway spruce (*Picea abies*), tsuga (*Tsuga sieboldii*), and sawara (*Chamaecyparis pisifera*)[48] had strong effects on *D. farinae*. The leaf oils of shirodamo (*Neolitsea sericea*)[47] and hinoki (*Chamaecyparis obtusa*)[49] had an acaricidal effect on *D. pteronyssinus* and *D. farinae*.

Analysis of the components of these leaf oils showed that piperitone and citronellal, which are the principal components of *Euclyptus dives* and *E. citriodora* leaf oil;[45] terpinen-4-ol, α-terpinyl acetate, and elemol in hinoki-asunaro leaf oil;[46] methyl salicylate in wintergreen;[35] and isosericenine, caryophyllen oxide, and α-cadinol in shirodamo leaf oil[47] were highly effective in killing mites.

Effects of wood oils on house dust mites

In an experiment on wood oils, Takaoka et al.[50] kept *D. pteronyssinus* and *D. farinae* in a mixture of culture media and sawdust from seven species of wood commonly used as construction materials, and counted the number of living mites every 10 days. The number of living mites in the mixture decreased sharply, and it was found that the oils of hinoki, sugi (*Cryptomeria japonica*), Douglas fir (*Pseudotsuga menziesii*), eastern red cedar (*Juniperus virginiana*), and western red cedar (*Thuja plicata*) strongly suppressed the spread of the mites. They also found that the oils of Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) had little effect on the mites, and that the effect of hinoki sawdust with extractives removed was noticeably weaker than the effect of untreated hinoki sawdust. In addition, they showed that the numbers of living mites exposed to volatiles from hinoki wood oil decreased sharply.

Miyazaki[51] prepared mixtures of culture media and hiba (*Thujopsis dolabrata* var. *hondai*) sawdust from which oil was extracted. He raised *D. pteronyssinus* in the mixtures with the oil concentrations adjusted to 0%, 0.25%, 0.50%, 1.0%, 2.0%, 4.0%, and 8.0%, and observed the reactions of the mites. The mite population increased eightfold within 25 days in the media of 0% hiba wood oil concentration, but the percentages of moving mites decreased drastically with exposure to 2.0%, 4.0%, and 8.0% wood oil, and no moving mites were observed after 48h. The percentages of moving mites after exposure to 0.25%, 0.50%, and 1.0% wood oil were 7% after 25 days, 0% after 20 days, and 0% after 13 days, respectively. Miyazaki showed that higher wood oil concentrations had stronger suppressive effects on the activity of the mites. These results suggest that wood oils have certain components with the ability to kill mites, and that these components differed depending on the species of wood.

The effects of wood oils on mites were also examined, and it was found that the essential oils of hinoki,[45] hiba,[45,51–53] Douglas fir,[45] western red cedar,[45] houshou,[35] *Chamaecyparis taiwanensis*,[53] *Taiwania cryptomeriodes*,[54] and yakusugi (a variety of *Cryptomeria japonica*) bogwood[55,56] had strong effects on the activity of house dust mites. Analysis of the components of these oils showed that α-cadinol and T-cadinol in hinoki wood oil,[57] linalool in houshou,[35] α-cadinol in *T. cryptomeriodes* wood oil,[54] and β-eudesmol, cedrol, and thujopsen in yakusugi bogwood oil[55] were very effective in killing mites. The effect of hiba wood oil[51] on mites was thought to be related to thujopsene and cedrol, the principal components of hiba wood oil. Although the sensitivity of *D. pteronyssinus* and *D. farinae* to these leaf and wood oils differed,[35,45,47,52,55] in both species males were more sensitive to them than females.[45,52,55]

Use of essential oils in homes to control house dust mites

It has been shown experimentally that some plant and wood oils and their components have a suppressive effect on the activity and development of house dust mites.[35–55] However, when these materials are actually used in homes, the essential oils volatilize easily and it is difficult to retain a long-lasting effect on mites. It is therefore necessary to give them and their components the ability to volatilize gradually so that the effects are continuous.

In order to develop a practical method for using the essential oils, McDonald and Tovey[58] examined the ability of five essential plant oils, citronella (*Cymbopogon nardus*), eucalyptus, spearmint, tea tree (*Melaleuca alternifolia*), and wintergreen oils, as laundry additives to kill house dust mites. They suggested that dilute solutions of essential oils were potentially an effective, acceptable, and inexpensive method of controlling mites. Tovey and McDonald[59] also reported that in laboratory experiments, more than 80% of a population of the house dust mite *D. pteronyssinus* was killed after immersion in 0.2% and 0.4% solutions of eucalyptus oil for 30 and 60 min, and that machine-washing woolen blankets in a 0.2% eucalyptus oil solution for 30 and 60 min killed 97% and 99% of mites, respectively.

Yamamoto et al.[60] added hinoki, hiba, and *Chamaecyparis taiwanensis* to carpet cleaner and showed that they had a suppressive effect on the activity of *D. pteronyssinus*. Moreover, microcapsules from the essential oils of hinoki and yakusugi were prepared using a spray-dry method to give them the ability to volatilize their components gradually so that they had a continuous effect on mites.

The effective periods of volatiles from these oils on the activity of *D. pteronyssinus* were also examined. Microcapsules made from hinoki and yakusugi wood oils retained their ability to kill mites for about 6 months in the case of hinoki and a year in the case of yakusugi.[61] These results showed that it was possible to use essential oils in homes to control house dust mites.

Effects of volatiles from wood chips, veneers, and wood-wool on house dust mites

The effects of volatiles directly from wood on mites were also investigated. Enomoto et al.[114] used eastern red cedar balls (diameter 7 mm) and chips and found that their volatiles repelled *D. farinae*. Hiramatsu and Miyazaki[115] investigated the effect of volatiles from chips of six species of wood, hinoki, hiba, sugi, kusunoki (*Cinnamomum camphora*), mizunara (*Quercus crispula*), and keyaki (*Zelkova serrata*). First, they prepared exposure chambers that had air holes, and put *D. pteronyssinus* in. Then they placed the exposure chambers on the wood chips. *Dermatophagoides pteronyssinus* inside the exposure chambers were kept off the wood chips, and were exposed to the volatiles from the chips that came inside the chambers through the air holes. They found that of the softwoods, hiba and hinoki chips strongly suppressed the activity of the mites, and sugi had a slight suppressive effect. Of the hardwoods, only the kusunoki suppressed mite activity strongly.

To examine the suppressing effect of volatiles from wood on house dust mites in homes, Mori and Miyazaki[116] prepared tatami mats, where mites tend to breed, embedded with softwood veneers and observed the effects on *D. pteronyssinus*. They found that the volatiles from the hiba and hinoki veneers strongly suppressed walking and moving of the mites, and that sugi moderately suppressed it.

In addition, Hiramatsu and Miyazaki[117] measured the period for which softwood veneers embedded in tatami mats were effective against *D. pteronyssinus*, using tatami mats of the same specifications as those used in the study by Mori and Miyazaki[116] by conducting 5-day exposure tests every few weeks for a total of 54 weeks. They also found that the volatiles from hiba and hinoki veneers suppressed the activity of the mites for 54 weeks and 11 weeks, respectively.

In another study, Hiramatsu et al.[118] prepared a tatami mat consisting of hinoki wood-wool, and measured the suppressive effect of volatiles from them on the activity of *D. pteronyssinus* by conducting 5-day exposure tests every few weeks for a total of 52 weeks. They showed that the suppressive effect of the volatiles from hinoki wood-wool on mites was maintained for 52 weeks.

Prospects of controlling house dust mites by using wood

Effective means of controlling house dust mites that cause allergic diseases include daily cleaning of rooms, washing, and indoor humidity control. In addition, recent research on house dust mite control using essential oils and their components of wood has received much attention. More basic data should be acquired and research conducted on practical applications.

Clarifying the effects of wood volatiles and oils in suppressing house dust mites makes it possible to develop acaricides and a variety of wood-based materials for controlling mites, and to create new applications for wood in daily life. The use of wood and wood-based materials will help to improve indoor environments, control house dust mites, and increase human comfort. However, field testing will be required to measure these effects and the effective period on mites and the amount and the composition of wood volatiles in air.

If wood volatiles are to be used in daily life for controlling house dust mites, in addition to their effects on mites, their influence on humans should also be considered, because humans and house dust mites usually live in the same space. In some studies, sensory evaluations conducted to investigate the psychological effects of hinoki and hiba wood oils found that the smell of hinoki and hiba was considered natural and refreshing.[60,119] Hiramatsu et al.[117] showed that the smell of softwood chips, hinoki, hiba, and sugi, which had suppressive effects on mites, were considered refreshing and unexciting, and those of hiba and sugi were also considered natural.

Recently, it has been reported that the odor stimuli of both α-pinene and limonene, which are volatiles of wood, decreased systolic blood pressure and induced comfortable feelings in humans.[120,121] However, even if the smell of wood is comforting, the influence of long-term exposure of humans to wood volatiles is not clear at present, and this should be examined. There is not enough basic data on the influence of wood oils and volatiles on humans at the current time, and further research is called for. Collaborative research with other fields, such as medicine, will become important in the future.

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