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RESEARCH ARTICLE

House dust mites eradication treatments: Current updates emphasizing on tropical countries

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ABSTRACT

House Dust Mites (HDMs) like *Dermatophagoides farinae (D. farinae), Dermatophagoides pteronyssinus (D. pteronyssinus) and Blomia tropicalis (B. tropicalis)* were found all over the world. Their relationship with allergy diseases was one of the focal points of epidemiological investigations spanning various geographical regions globally but specifically in regions with warm temperatures. Their omnipresence underscores their pivotal role in the etiology and exacerbation of some respiratory disorders, emphasizing their significance as environmental allergens. Despite the availability of numerous eradication treatments ranging from sun exposure to ozone-based approaches, the quest for efficacious HDM eradication encounters obstacles due to the diversity in study methodologies employed to evaluate these different intervention strategies. This methodological heterogeneity complicates the quantification of treatment efficacy, impeding the establishment of definitive criteria distinguishing "effective" from "ineffective" approaches. Despite the urgency of developing solutions, current efforts are hindered by this lack of consensus. This review aims to bridge this gap by synthesizing existing knowledge on HDM eradication strategies and discussing their efficacy, safety, and practicality. By addressing these discrepancies, this article endeavors to provide insights and clues for the future development of evidence-based interventions aimed at mitigating HDM infestations and ultimately reducing its sensitization rate worldwide.

Keywords: House Dust Mites (HDMs); allergy; asthma; ozone treatment; sensitization.

INTRODUCTION

Diverse types of mites existed including House Dust Mites (HDMs), storage mites, bird mites, and fur mites. Mites were widely recognized for their hyper-diversity, with over 55,000 identified species worldwide but the actual number of mite species was anticipated to exceed this already substantial count (Meng *et al.*, 2021). Nevertheless, the leading species in terms of prevalence and abundance on a global scale were HDMs mostly belonging to the Pyroglyphidae family which consisted of 47 species, including *Dermatophagoides farinae (D. farinae), Dermatophagoides pteronyssinus (D. pteronyssinus), and Euroglyphus maynei (E. maynei)* (Sarwar, 2020).

HDMs were ubiquitous globally, and they were the most common cause of respiratory allergies worldwide (Ciprandi *et al.*, 2017). The association between HDMs and allergic diseases such as hay fever, rhinitis, asthma, and conjunctivitis has been long-established (Tang *et al.*, 2011). A study showed that children with strong sensitization to HDMs at 8 to 9 years faced the highest risk of asthma and allergic rhinitis (Gabet *et al.*, 2019). This highlighted the significant role of HDM allergy in contributing to respiratory issues, particularly asthma. Presently, asthma is one of the most common non-communicable respiratory diseases, affecting more than 300 million people worldwide, and the number is suspected to keep growing (Caminati *et al.*, 2021). Additionally, during the global lockdown due to the COVID-19 pandemic, being quarantined at home for weeks increased exposure to dust mites, exacerbating the allergy burden of HDMs worldwide and potentially leading to further aggravation of respiratory diseases such as allergic rhinitis and asthma (Gelardi *et al.*, 2020). This increased prevalence of sensitization might be influenced by some lifestyle changes like insufficient sunshine and poor ventilation in the living area (Li *et al.*, 2021).

Numerous factors could contribute to HDM allergies, including genetic predisposition. Children born into families with a history of atopy may face an elevated risk of sensitization to environmental allergens and a greater likelihood of developing HDM allergy (Zolkipli *et al.*, 2015). Geographical regions also played a role, as regions with warm and humid climates were more optimal for mite proliferation, thus increasing the risk of sensitization (Acevedo *et al.*, 2019). Socioeconomic position (SEP) was identified as another factor that could contribute to HDM allergies. A systematic review in the United Kingdom found that the prevalence of allergies was associated with higher SEP. It was proposed that the elevated frequency of allergies in individuals with higher socioeconomic status was linked to the hygiene hypothesis, which suggested that reduced early childhood

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exposure to infections heightened susceptibility to allergies (Uphoff *et al*., 2015). Whether this observation in the UK applied to tropical countries remains to be investigated.

Understanding house dust mites (HDMs) is crucial as they affect 65-140 million people worldwide (Huang *et al*., 2023). Addressing gaps in knowledge about their epidemiology, health effects, and management underscores the need for evidence-based eradication methods. While various methods to kill HDMs exist, including acaricides, humidity control, sunlight exposure, vacuuming, and ozone treatment, determining the most effective eradication method remains challenging (Gøtzsche *et al*., 1998). Therefore, this paper aims to address these knowledge gaps by exploring the epidemiology, and health implications, and evaluating the efficacy of different treatment options for HDM infestations.

Epidemiology of dust mite

In the context of HDM epidemiology, factors like humidity and geography were explored to understand why certain areas had higher susceptibility to HDM allergy. Examining prevalence rates and distribution patterns across demographics, epidemiology informed targeted interventions to mitigate dust mite allergy's impact. Recognizing the relevance of epidemiology was crucial as it provided essential context for assessing HDM allergy prevalence, distribution, and risk factors, informing the development of effective management strategies and interventions.

Among the two predominant species, *D. pteronyssinus* and *D. farinae,* prevalence rates varied geographically. In temperate regions, *D. pteronyssinus* tended to be more prevalent, while *D. farinae* was more common in warmer climates (Arlian *et al*., 1992). These mites thrived in conditions exceeding 50% relative humidity, with concentrations peaking at 70%. The ideal temperature for HDM growth ranged from 18 to 24°C (Huang *et al*., 2023). Furthermore, in very humid housing conditions, storage mites such as *Lepidoglyphus destructor*, *Tyrophagus putrescentiae*, and *Glycyphagus domesticus* were often found in house dust (Vrtala, 2022). *Blomia tropicalis (B. tropicalis)* which was initially categorized as a storage mite, was subsequently reclassified as a HDM within the superfamily Glycyphagidae (Guilleminault & Viala-Gastan, 2017). In tropical regions, *B. tropicalis* was among the most frequently found species of HDMs (Hubert *et al*., 2023). Geographical factors played a crucial role in the prevalence of dust mite allergies. In Southeast Asia, including tropical countries like Singapore and Malaysia, where warm and humid climates prevailed, dust mite populations thrived. The high humidity levels and relatively constant temperatures created an ideal habitat for dust mites, contributing to increased prevalence rates of dust mite allergies in these regions (Lee *et al*., 2023).

HDMs were considered the most prevalent aeroallergen affecting allergic individuals in Asian countries. The sensitization rate range and associated Asian countries are summarized in Table 1.

Table 1 depicts varying rates of house dust mite (HDM) sensitization among allergic individuals in different Asian countries. Malaysia, Singapore, Taiwan, and South India showed high rates (>70%), while North India, Vietnam, and the Philippines exhibited lower rates (<50%). This suggested regional differences in HDM allergy prevalence across Asia. *D. pteronyssinus* aeroallergens played a role in atopic sensitization in 50–85% of asthmatics and were recognized as significant inducers of allergenicity worldwide (Abu Khweek *et al*., 2020). However, in Malaysia, research indicated that a significant portion of the population showed sensitization to *D. pteronyssinus* and *D. farinae,* with prevalence rates of 35% for *D. farinae* and 37% for *Glycycometus malaysiensis.* This contrasts with findings in other regions, where *D. pteronyssinus* was more common (Chong *et al*., 2015).

Table 1. Prevalence of HDM sensitization in Asian countries

Country	Sensitization Rate Range	Reference
Singapore	70%–90%	(Tham *et al*., 2016)
Taiwan	85%–90%	
South India	89.7%	
North India	7.8%	
Vietnam	9%–23%	
Philippines	33%–47%	
Malaysia	60%–80%	(Lee *et al*., 2023)

Current trends showed shifts in sensitization patterns, with increasing rates observed in urban developed regions of Asia-Pacific, Africa, and Latin America, suggesting a correlation with economic development, urbanization, and climate factors (Acevedo *et al*., 2019). Moreover, equatorial countries like Zimbabwe had high dust mite populations probably due to consistent warmth and humidity which could lead to elevated allergy rates as compared to temperate countries like Austria (Caraballo *et al*., 2016). Unlike regions with distinct seasons, where dust mite populations may fluctuate with changing environmental conditions, equatorial countries maintained consistently high levels of dust mite allergens due to the perpetual warmth and humidity. As a result, individuals living in equatorial regions were more likely to be exposed to HDM allergens year-round, increasing their risk of developing dust mite allergies compared to those in other climatic zones.

It was evident that HDMs thrived in tropical and equatorial regions of the Earth due to the warm, consistent climate and high humidity. As global warming progresses, the tropical regions might extend and expand to encompass larger geographical areas, creating an even more favorable environment for dust mites to thrive and proliferate (Acevedo *et al*., 2019). Figure 1 illustrates the potential impact of global warming on the expansion of HDM habitats.

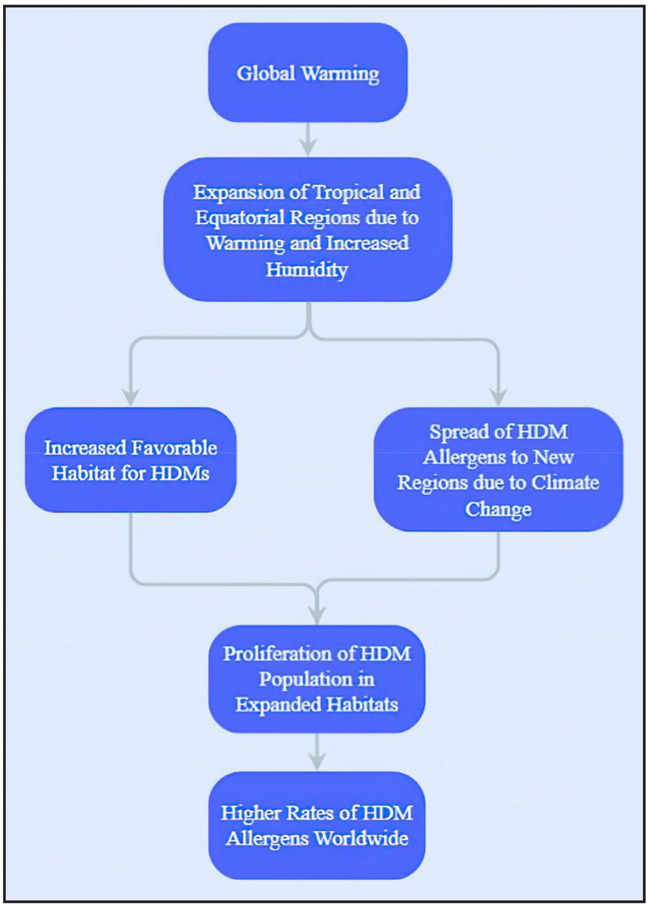


Figure 1. Impact of Global Warming on House Dust Mites (HDMs) Habitat Expansion (Acevedo *et al*., 2019).

Table 2. Common responses of organisms to global warming

Organisms	Before Global Warming	After Global Warming	References
Mold Spores	Flourished in damp and humid environments, often found in basements and bathrooms.	Increased prevalence in previously dry or cooler regions as humidity levels rise and temperatures become more conducive to mold growth	(Zingales *et al*., 2022)
Cockroaches	Prefers warm and humid environments, often found in tropical regions.	Expanded their range to cooler climates as temperatures rise, leading to increased infestations in previously unaffected areas	(Patel & Meher, 2016)
Mosquitoes	Typically found in tropical and subtropical regions due to their preference for warm temperatures and stagnant water.	Expanded their distribution to higher latitudes as warmer temperatures allow for longer breeding seasons and increased survival rates	(Rossati, 2016)
HDMs	Commonly found in warm, humid indoor environments such as bedding, carpets, and upholstered furniture.	Increased prevalence and extended geographic range, with higher populations in previously cooler and drier regions as global temperatures and humidity levels rise	(Acevedo *et al*., 2019)

Similar responses to global warming were observed in other organisms, such as mold spores, cockroaches, and mosquitoes. These organisms thrived in warm and humid environments and were expected to expand their ranges and increase their populations as temperatures rose. Table 2 summarizes the responses of these organisms to global warming. The range of years concerning global warming typically spans from the late 20th century to the present, with significant temperature rises observed since the 1980s. The data in Table 2 are affected by long-term climate trends that have been documented over recent decades.

The epidemiology of house dust mite (HDM) allergies highlighted the significant influence of environmental factors and geography on their prevalence and distribution. Studies indicated that humidity and temperature were crucial determinants, with warm and humid regions such as Southeast Asia and equatorial countries experiencing higher prevalence rates. For instance, increasing global temperatures were linked to the expansion of tropical environments, milder winters in higher latitudes, and subsequently, higher HDM concentrations and exacerbated asthma symptoms (Acevedo *et al*., 2019). Humidity plays a vital role in HDM growth and survival, affecting reproduction and allergen production, with rising global temperatures expected to increase indoor humidity and allergic symptoms. Additionally, urbanization and air conditioning influenced indoor HDM exposure and humidity levels, with urbanization linked to higher sensitization rates and air conditioning potentially promoting moisture accumulation despite reducing humidity.

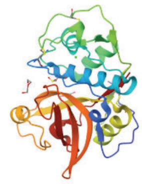
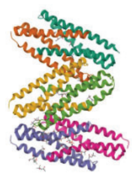
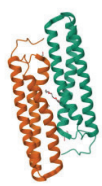
Diseases and problems associated with dust mite

HDM allergy was a global issue, comparable to diseases like malaria and dengue fever. Unlike these diseases transmitted by mosquitoes, HDM allergy wasn't spread by a vector or agent. Instead, it resulted from exposure to allergens produced by the mites themselves, with mite feces being a major source of these allergens (Jacquet, 2021). It was found that more than 95% of allergen content was found in a culture containing whole mites, cuticles, and feces. This finding highlighted the significant contribution of mite feces to the overall allergenicity of house dust. The allergen production process in dust mites began within their digestive system. As dust mites fed on organic matter in dust, they ingested proteins from sources like human skin scales, animal dander, pollen, and fungal spores, along with substances like dust mite feces and microorganisms. These substances, including proteins such as keratins from human skin scales, albumin from animal dander, and various plant proteins, were digested in the mite's gut. Carbohydrates and lipids from organic matter were then metabolized, leading to the production of enzymes such as proteases and chitinases. These enzymes accumulated in fecal pellets as the mite progressed through the digestive tract. Eventually, dehydrated mite cells and fecal pellets containing a concentrated mixture of allergenic proteins were expelled from the hindgut, forming pellets that could trigger allergic reactions in sensitive individuals (Colloff, 2009). Other allergens like shed exoskeletons which also contained allergenic proteins, when combined with the fecal pellets could become airborne in indoor environments having similar properties to pollen grains, these particles could be deposited on the nasal mucosa and other respiratory surfaces during inhalation (Tovey *et al*., 1981). This process was part of the allergic cascade, wherein the immune system overreacted to otherwise harmless substances, resulting in allergic reactions (Ghorai & Kaur, 2022). Table 3 summarizes some of the major groups of HDM allergens and their characteristics in descending order of IgE reactivity hierarchy, from top to bottom (Thomas, 2016).

Asthma

The relationship between HDMs and asthma was established long ago. For example, a study in the Ecuadorian Andes found that out of 433 asthmatic children, the most sensitizing allergens were HDMs allergens with more than 70% of the asthmatic children sensitized to HDMs allergens (Valdivieso *et al*., 1999). A group of Egyptian scientists investigated the association between HDM sensitization and the level of asthma control in asthmatic children. They discovered that HDM sensitization increased asthma severity and reduced the ability to control asthma symptoms such as coughing and sneezing (Okasha *et al*., 2021). These findings justified the role of HDM allergens in asthma, highlighting the potential role of environmental interventions in managing asthma, particularly in individuals sensitive to HDM allergens. Interestingly, a study was conducted to investigate the impact of HDM-driven asthma on children's school performance, revealing that allergic asthma due to HDMs resulted in school/work and activity impairment in children, adolescents, and their caregivers. This suggested that HDM-driven asthma not only affected the daily activities of affected individuals but also had significant consequences on their academic performance (Gómez *et al*., 2022). These findings underscored the global burden of asthma, revealing a continual increase in prevalent cases from 1990 to 2019, as documented by Wang *et al*. (2023). Over this period, the number of prevalent cases rose significantly from 226.9 million to 262.41 million (Wang *et al*., 2023). This escalation highlighted the urgent need for comprehensive strategies to manage and prevent asthma.

Table 3. Major Groups of HDM Allergens and Their Structures and Functions

Group	Protein Name	Type	Characteristics	Examples of HDM Allergen Crystal Protein Structure from Protein Data Bank (PDB)	References
1	Der p1	Cysteine protease	Breaks down the epithelial barrier, activates immune cells via protease-activated receptors (PARs), and disrupts immune regulation.	 PDB Accession Number: 3F5V	(Asokananthan *et al*., 2002) https://doi.org/10.2210/pdb3F5V/pdb
2	Der f2	Immunoglobulin-like protein	Mimics MD-2, interacts with toll-like receptor-4 (TLR-4), activates innate immune system.	 PDB Accession Number: 1AHM	(Hu *et al*., 2022) https://doi.org/10.2210/pdb1AHM/pdb
23	Der p23	Chitin-binding protein homologue	Binds to chitin, a part of the HDM exoskeleton. It may contribute to allergic response.	 PDB Accession Number: 4ZCE	(Resch *et al*., 2016) https://doi.org/10.2210/pdb4ZCE/pdb
4	Blo t 4	Alpha-amylase	Found in house dust mite extracts and may contribute to allergic reactions in sensitized individuals.	N/A	(Thomas *et al*., 2004)
5	Der p5	Unknown with coiled-coil bundle structure	Structural part of house dust mite particles.	 PDB Accession Number: 3MQ1	(Thomas, 2016) https://doi.org/10.2210/pdb3MQ1/pdb
7	Der f 7	LPS-binding protein	Binds to lipopolysaccharides (LPS), potentially involved in immune response modulation.	 PDB Accession Number: 3UV1	(Mueller *et al.,* 2010) https://doi.org/10.2210/pdb3UV1/pdb
21	Der f 21	Group 5 homologue	–	 PDB Accession Number: 5YNX	(Thomas, 2016) https://doi.org/10.2210/pdb5YNX/pdb

Atopic Dermatitis (AD)

AD represented another worldwide concern that impacted approximately 5–20% of children and 2–8% of adults (Bumbacea *et al*., 2020). One study analyzed HDM populations in the mattresses of 23 AD patients compared to 23 healthy non-atopic individuals. It found significantly higher mite densities in AD patients. This showed that AD patients were exposed to higher mite densities, suggesting a strong association between mite exposure and AD (Colloff, 1992). Another study in the United Arab Emirates in 2008 found that 74.5% of AD patients were sensitive to HDM allergens and a strong correlation between the severity of the disease and its persistence with hypersensitivity of AD, proving the role of HDM allergens in AD (Adham *et al*., 2011). Studies concluded that HDM Group 1 allergens were proteolytic and could compromise skin barrier function which was one of the hallmarks of AD (Nakamura *et al*., 2007). Due to the disruption of the skin barrier, proteins from airborne allergens could easily penetrate the epidermis, where they encountered allergen-presenting dendritic cells, triggering the Th2 allergic systemic inflammatory response and exacerbating the severity of AD (Steinhoff *et al*., 2003). To conclude, the role of HDM allergens in AD was clear and the activity of AD could be greatly reduced if the level of HDM allergens was reduced (Tan *et al*., 1996).

Other diseases

Diseases such as conjunctivitis, urticaria, and allergic rhinitis might also be provoked by HDM allergens (Miller, 2019). Recent studies delved into the association between HDM sensitization and basophil reactivity in chronic spontaneous urticaria (CSU). Basophil-enriched leukocytes isolated from CSU patients revealed heightened expression of CD63 and FcεRIα, alongside elevated HDM-specific IgE levels (Liang *et al*., 2023). Moreover, in an atopic keratoconjunctivitis mouse model, the dose-dependent exacerbation of eosinophilic inflammation in conjunctival tissues following HDM antigen application underscored the HDMs' allergen's role in allergic responses (Shiraki *et al*., 2021). A study involving 2972 children with allergic conjunctivitis found that HDMs were the most common allergen, affecting 43.41% of the participants. The study also noted that as children aged, the positive rate for inhaled allergens increased, while the rate for ingested allergens decreased. Additionally, higher levels of HDM-specific IgE (sIgE) were associated with an increased number of allergic comorbidities and a higher risk of polysensitization (Tang *et al*., 2024).

Interestingly, a study in France showed some connections between HDM allergens and Inflammatory Bowel Disease (IBD). Abnormal gut barrier function underpinned gut inflammatory diseases, and HDM aeroallergens were known to induce inflammation in respiratory mucosa. Recent findings showed that allergens from *D. pteronyssinus* specifically Der p1 were present in the rodent gut. This presence of Der p1 in the gut suggested a possible link between environmental allergens and gut-related inflammatory conditions, like IBD, triggering gut dysfunction (Tulic *et al*., 2016).

In patients with allergic rhinitis, HDMs allergens often caused nocturnal respiratory impacts and diminished quality of life (QOL). Sleep disturbances, particularly during the Rapid Eye Movement (REM) sleep stage, were common among patients with allergic rhinitis (AR). Those sensitized to house dust mites (HDM) exhibited elevated REM-related respiratory disturbance indices (REM-RDI) as proved by a retrospective study of 100 patients, including 47 HDM-positive cases that found a significantly higher likelihood of moderate to severe REM-related Sleep Disordered Breathing (SDB) among those allergic to HDM (Berson *et al*., 2020). In fact, the use of the Allergen Control Chamber (AEC) provided controlled environments for precise exposure to house dust mite (HDM) allergens, facilitating standardized assessments of allergic symptoms and treatment responses in clinical research and therapeutic trials (Zemelka-Wiacek *et al*., 2023).

This controlled setting not only enhanced our understanding of the impact of HDM allergens on allergic diseases like allergy rhinitis but also supported the real-world data showing that subcutaneous allergen immunotherapy (AIT) with HDM mite allergoid effectively managed allergic rhinitis and asthma that showcased significant reductions in medication dependency over an extended follow-up period (Jutel *et al*., 2020). These findings underscored the critical role of HDM allergens in perpetuating allergic diseases and the potential of AIT as a therapeutic intervention for HDM-induced allergies.

Treatments

Methods to eradicate HDMs included both physical and chemical methods. Here, we discussed some of the studies that investigated these approaches.

Sunlight, humidity, and UV

Sunning bed sheets or furniture to kill dust mites was indeed effective. Dust mites required humidity above 65% to survive, so direct sunlight reduced humidity levels, making it inhospitable for them. High temperatures and low humidity accelerated moisture loss from mites, leading to dehydration and death (Portnoy *et al*., 2013). Reduced relative humidity levels impeded dust mite reproduction and constrained their ability to flourish in the environment. For instance, in a study where dust mites were subjected to dry conditions with fluctuating relative humidity between 38% and 60%, every mite perished within 18 days. This differed from mites exposed to damp conditions, where relative humidity fluctuated between 55% and 70%, or optimal conditions at a relative humidity of 75%, resulting in no significant difference in survival and development (Pike *et al*., 2005). A group of researchers from Australia discovered that direct sunlight exposure could affect the morbidity of HDMs. They conducted a study where woolen carpets were exposed to sunlight for hours, monitoring conditions underneath. During exposure, they noted a notable decrease in live mite populations and a rise in dead mites. This indicated sunlight created a hostile environment for dust mites. Notably, no live mites were found in the last 3 hours when the carpet's temperature reached 55°C, and humidity dropped to 24% (Tovey & Woolcock, 1994). This research provided empirical evidence supporting the traditional practice of sunning textiles as a means of controlling dust mite populations, offering a simple and effective strategy for households looking to mitigate allergen exposure. In Thailand, researchers found a significant decrease in egg hatching percentage, reaching total egg destruction after 3 to 5 hours of exposure to direct sunlight while the control group exhibited a hatching rate of 98%, further showing the killing effect of direct sunlight on HDMs (Mahakittikun *et al*., 2011). Besides direct exposure to sunlight, we could also infer that controlling humidity levels in households could contribute to reduced dust mite levels. For example, one study aimed to assess the impact of maintaining indoor relative humidity below 51% on HDMs and allergens found significant reductions in live mite populations and allergen levels in the low relative humidity group as compared to other groups (Arlian *et al*., 2001).

Maintaining humidity and ventilation in indoor environments played a crucial role in controlling HDM populations (Pei *et al*., 2020). By ensuring adequate airflow and maintaining indoor humidity below 50%, particularly in areas prone to moisture buildup such as bathrooms, kitchens, and basements, the risk of HDM infestations could be reduced. Regularly monitoring with hygrometers and adjusting ventilation systems ensured optimal conditions for controlling HDM populations (Seppהnen & Kurnitski, 2009). While maintaining humidity and ventilation required ongoing attention and effort, it served as an integral component of integrated pest management strategies aimed at reducing HDM infestations and minimizing associated allergic symptoms.

Sunlight's major component, ultraviolet light (UV), was divided into UV-A, UV-B, and UV-C regions. UV radiation, in general, could cause DNA damage, leading to cell death. Among these, UV-C, with the shortest wavelengths, was the most potent and utilized for its germicidal effects in the medical, industrial, and agricultural sectors (Sadhukhan, 2019). In the agricultural sector, UV-C irradiation has been utilized in the management of *Tetranychus urticae,* commonly known as the two-spotted spider mite, which is considered one of the most economically important pests worldwide (Short *et al*., 2018). UV-C irradiation was also proven to be lethal to stored-product mites like *Tyrophagus putrescentiae* (Bakr, 2013). These studies highlighted the potential applicability of UV radiation, in controlling pests like HDMs. There was some ongoing research around the world that studied the acaricidal effect of UVC on HDMs. For example, a study conducted in America tested two exposure times against newly laid *D. farinae* eggs. Results showed that none of the UV-C-exposed eggs hatched, while most control eggs did. Scanning electron micrographs revealed that many of the UV-C exposed eggs collapsed by day 8, with no larval mites emerging. This suggested that UV-C irradiation could disrupt the life cycle of HDM by killing the embryonic stage, potentially halting allergen production (Needham *et al*., 2006). Another study conducted in Malaysia demonstrated the effectiveness of UV-C irradiation in killing HDMs (HDMs), specifically *D. pteronyssinus* and *D. farinae.* Their findings revealed the highest immediate mortality of 100% was achieved with direct irradiation at 10 cm from the UV-C lamp for 60 minutes. The study concluded that the mortality of irradiated mites was directly proportional to the exposure times but inversely related to the distances (Lah *et al*., 2012). While UV light showed promise in killing mites, further research was necessary to determine its practical use. The limited penetration of UV-C radiation through substrates posed a challenge, reducing its effectiveness in eliminating dust mites hidden in dense fabrics, mattresses, or carpets, as the reach of UV-C light was restricted by distance (Lah *et al*., 2012).

The sunning approach might be the most effective for people in rural areas due to their greater access to outdoor space compared to urban residents. Rural households often have larger outdoor areas where bedding and other items can be exposed to sunlight, facilitating effective HDM control through natural means. However, in urban areas with limited outdoor space, using the sunning technique might be challenging and less practical.

Overall, understanding HDMs' reaction to sunlight led to the development of targeted strategies like phototherapy that utilized UV radiation to disrupt mites' cellular structure, causing their demise, and some insights into managing ventilation and airflow to control HDM populations.

Vacuuming

Vacuuming was another common way to get rid of HDMs. A study was done to assess the effectiveness of daily vacuum cleaning in reducing house dust mite allergens, bacterial endotoxin, and fungal β-glucan. Twenty volunteers vacuumed their mattresses daily for 8 weeks, with dust samples analyzed for allergens and contaminants. Results indicated a significant reduction in allergens and contaminants, with percentage reductions ranging from 71.0% to 85.1%. This study showed that daily vacuuming was a practical and cost-effective method for atopic patients to reduce indoor allergens (Wu *et al*., 2012). Another study that aimed to investigate the frequent vacuum cleaning of Der p 1, the major allergen of *D.pteronyssinus* found a progressive decline in Der p 1 concentration over the study period, with a mean reduction of 48.0% in dust samples and 68.5% per unit area suggesting that frequent vacuum cleaning significantly reduced house dust mite allergen levels in carpets (Adilah *et al*., 1997). Although there were some pieces of evidence supporting vacuuming as an effective way to eradicate HDMs, several studies showed otherwise. For example, a study investigated the efficacy of vacuuming in removing HDMs from carpeted surfaces, finding that prolonged vacuuming was not highly efficient as the initial few minutes yielded the most significant results. Despite vacuuming successfully extracting some mites, the reduction in mite populations was minimal (Wassenaar, 1988). In Australia, a study examined the effect of vacuum cleaning on the distribution of the dust mite allergen Der p 1 in household carpets. Results revealed differing Der p 1 concentrations across carpet layers, indicating that vacuuming did not consistently reduce allergen levels but altered their distribution (Sercombe *et al*., 2007).

Vacuuming was arguably the easiest if not, the most accessible way of controlling HDM populations in indoor environments. Vacuuming should have been carried out in conjunction with other eradication techniques because it helped to physically remove dust mites, their eggs, and allergen-containing debris from indoor surfaces. For example, when used alongside acaricides, vacuuming could have enhanced the overall efficacy of the treatment by reducing the initial mite burden and creating a cleaner environment for the acaricides to act more effectively (Schober *et al*., 1992). Combining vacuuming with other methods such as dry steam cleaning might also enhance its effectiveness, as demonstrated by Ho Yu *et al*. (2009).

Chemical means

Chemicals with acaricidal properties, referred to as acaricides, were commonly used to eradicate HDMs. In a comparative study of nine acaricides, Acarosan powder and liquid nitrogen, combined with vacuuming, were identified as the most effective treatments. Acarosan powder demonstrated the highest efficacy, nearly eradicating dust mites on various surfaces like mattresses, carpets, and wooden boards. Liquid nitrogen also showed significant acaricidal activity, particularly on mattresses and carpets. Paragerm and Actelic 50 followed in effectiveness, succeeded by Acardust and Acarosan foam. Tymasil exhibited lower efficacy, while Artilin formulations (aqueous and spirit) showed the least effectiveness in reducing dust mite populations (Schober *et al*., 1992). Acarosan powder, containing benzyl benzoate, stood out as highly effective in the study. In a trial across 22 households, solidified benzyl benzoate (bb) foam and powder significantly reduced dust mite allergen concentrations on mattresses and carpets. The study, conducted over 60 days with two applications, demonstrated benzyl benzoate's potential as a viable treatment option (Lau-Schadendorf *et al*., 1991). Paragerm which was another popular acaricide listed before, was tested for its effectiveness in controlling mattress mite populations. Compared to a control spray, Paragerm spray from either a hand-pressurized can or a general room mist device significantly reduced mite number after 1 month. However, some mites survived Paragerm treatment, and this could lead to re-infestation (Penaud *et al*., 1977). Interestingly, tannic acid, which could be derived from tea plants, was also considered as an acaricide, albeit temporarily, as it rapidly reduced the allergenicity of dust due to its protein-denaturing activity (Kalpaklioglu *et al*., 1996). In fact, in a comparative study assessing the efficacy between benzyl benzoate and tannic acid in reducing allergen levels in carpets, tannic acid showed superior effectiveness in decreasing the concentrations of Der f 1 and group 2 mite allergens compared to Der p 1 and cat allergens (Woodfolk *et al*., 1995).

Nonetheless, using acaricides to mitigate HDM infestation was not without its drawbacks as several studies showed using acaricides might only be a more temporary solution, and repeating applications were needed to control mite-allergen levels (Hayden *et al*., 1992). One study even suggested that neither Acarosan nor liquid nitrogen reduced the concentrations of Der pI for as long as six months after application. While a small effect was observed, it was likely of little clinical importance and transient, as the trend was lost by six months (Kalra *et al*., 1993). A study examined benzyl benzoate's impact on preventing mite colonization in new mattresses within 12 dust-mite-infested double beds. Despite treating new mattresses with benzyl benzoate or placebo and conducting frequent cleansing over 18 months, benzyl benzoate did not provide extra mite control benefits compared to placebo, as indicated by dust sample analysis, showing regular cleaning might play a more crucial role in managing HDM infestations (Rebmann *et al*., 1996).

One of the benefits of using acaricides to kill HDMs was convenience. However, research has shown that continued use might lead to resistance in dust mite populations. This resistance would reduce the effectiveness of acaricides and require alternative control methods. Some acaricides had adverse effects on the environment, including contamination of soil and water sources or harm to non-target organisms such as beneficial insects and wildlife (Pathak *et al*., 2022). Improper use of acaricides could pose health risks to humans and pets, including skin irritation, respiratory issues, and toxicity if ingested (Panis *et al*., 2022). Acaricides for HDM infestations yielded mixed results, reducing the populations of HDMs but not eradicating them. Temporary relief occurred, but sustained control needed repeated applications. Managing infestations effectively likely required a combination of approaches, including regular cleaning alongside acaricide treatments.

Ozone treatment

Ozone treatment, although potentially more effective and less costly, has been less explored for this purpose (Arlian & Platts-Mills, 2001). Ozone which is a reactive gas that possesses strong oxidizing properties could destroy organic matter, including dust mites and their allergens (Han *et al*., 2006). This reactivity made ozone a potential fumigant for eliminating HDMs (Pumnuan *et al*., 2020). Experiments done by researchers in Korea confirmed that ozone treatment could indeed inactivate HDMs. They investigated how ozone exposure affected house dust mites (HDMs), confirming that continuous ozone exposure deactivated them. At 0.48% ozone concentration or 4800ppm (25°C, 75% humidity), no live HDMs were seen after 40 minutes of exposure (initially 41–50 mites) (Han *et al*., 2006). In Thailand, a study demonstrated ozone treatment's efficacy against HDMs. Various ozone concentrations were tested on HDMs collected from mattresses in Bangkok households. Results showed that 3 hours of exposure to 30 mg/L or 30ppm ozone eliminated the mites, with 40 mg/L or 40ppm for 2 hours being the most effective treatment, achieving a 92.7% reduction (Pumnuan *et al*., 2020). In 2011, researchers from the Institute of Medical Research, Malaysia, tested ozone treatment on *Dermatophagoides farina* and *Dermatophagoides pteronyssinus*. They found that direct exposure to ozone in a controlled chamber significantly increased mite mortality rates within 6 to 24 hours whereas indirect exposure within a simulated mattress environment showed reduced efficacy over 24 to 72 hours compared to direct exposure, indicating that ozone treatment had lower effectiveness when HDMs were indirectly exposed (Abidin & Ming, 2012).

Studies showed that ozone treatment is a promising method to eliminate HDMs due to its effectiveness. However, it was important to note that most studies that used ozone treatment against HDM were done in laboratory settings. Based on the Malaysia Ambient Air Quality Standard (MAAQS), the recommended ozone levels should be lower than the limit of 0.1 ppm (Baidrulhisham *et al*., 2022). As such, some of the experiments carried out in the studies mentioned before had used ozone levels of more than 4000ppm making it unrealistic to apply directly to real-world scenarios due to safety concerns. This indicated that, despite some studies demonstrating the effectiveness of ozone treatment in reducing dust mite populations, its application in real-world settings faced significant challenges. Environmental factors such as humidity levels, air circulation, and other indoor pollutants significantly influence ozone's effectiveness in actual living spaces. Furthermore, safety considerations regarding ozone exposure must be carefully addressed to mitigate potential health risks to humans and pets. Evacuating the room during ozone treatment or ensuring proper ventilation afterward was essential due to safety concerns. This requirement potentially posed logistical challenges to the practical implementation of this approach. Equipment such as a Medklinn™ air ionizer could be utilized, with its emission levels controlled below 0.05 ppm, proven to effectively eradicate HDM populations while not causing harm to human health as mentioned before (Abidin & Ming, 2012). Similarly, other ionizers with comparable emission control capabilities might offer similar potential for eliminating HDMs. To summarize, while ozone treatment held promise as a novel approach to HDM eradication, further research was still needed to validate its efficacy and safety in the real world.

Advantages and limitations of HDM eradication methods

It was clear that HDM eradication techniques were multifaceted. Each has its advantages and limitations as shown in Table 4.

Table 4. Summary of Limitations and Advantages of the Various HDMs Eradication Techniques

Techniques	Limitations	Advantages	References
Sunning	• Depends on the weather (May not be applicable for countries with changing seasons). • Requires physical strength.	• Does not require chemicals or equipment. • Will not cause pollution.	(Tovey & Woolcock, 1994)
Vacuuming	• Requires repeated and thorough efforts.	• Removes dust and debris. • Easy application. • Can be easily incorporated into regular cleaning routines.	(Wu *et al*., 2012)
Acaricides	• May pose environmental concerns. • May need repeated application. • Can cause resistance. • Might cause allergy reaction.	• Kills HDMs but does not remove them. • Easy application. • Provides targeted treatment to specific areas. • Offers quick results with proper application.	(Mumcuoɔlu & ''zkan, 2020)
Maintaining humidity and ventilation	• Requires monitoring and adjustment.	• Helps control the HDM population. • Helps regulate indoor humidity level and reduces mold growth. • Enhances air circulation in living space.	(Sun *et al*., 2022)
Ozone	• Requires specialized equipment and trained individuals for installation.	• Provides comprehensive disinfection. • Eliminates odors and other airborne pollutants.	(Han *et al*., 2006)

Discrepancies, compliance, and future prospects

However, discrepancies among studies evaluating chemical and physical methods to reduce house dust mite allergens suggest these approaches might not be effective overall (Gøtzsche & Johansen, 2008). Variations in study design, methodology, and environmental factors make it challenging to pinpoint the most effective control method. For instance, differing concentrations and application methods for acaricides hinder direct comparisons. Standardizing protocols for concentration, frequency, and duration of exposure would enhance comparability. Environmental factors like humidity and temperature also influence HDM populations and intervention effectiveness, necessitating detailed environmental data and stratified results. Additionally, short-term studies may overlook the potential rebound of HDM populations, highlighting the need for long-term follow-up (e.g., 12 months or more). Future research should standardize methodologies, consider environ mental variables, and include long-term follow-up to provide conclusive evidence on the effectiveness of chemical and physical interventions.

Addressing challenges in the management of HDM allergy was essential for ensuring effective treatment outcomes and improved patient well-being (Arshad *et al*., 2017). Compliance emerged as a significant obstacle because successful management relied heavily on patient adherence to prescribed treatment regimens. Inconvenience, adverse effects, and perceived effectiveness might have influenced patient compliance, posing barriers to optimal treatment outcomes. Compliance was important because currently there was no permanent solution for eradicating HDMs.

Combining various methods simultaneously could improve the effectiveness of future HDM allergy management. This integration of physical and chemical treatments might offer synergistic effects, enhancing efficacy and reducing reliance on singular approaches, potentially leading to better patient outcomes (Omar *et al*., 2012). Since ozone treatment had demonstrated promising results in eradicating HDMs, further studies needed to be done to ensure its safety, particularly concerning exposure to ozone including potential adverse effects from ozone exposure (Smith *et al*., 2015). This was because high level of ozone exposure was associated with respiratory irritation, lung inflammation, and exacerbation of existing respiratory conditions in humans (Stober & Garantziotis, 2018). Comprehensive research into developing effective ozone treatment protocols for combating HDMs needed to be conducted and standardized to ensure efficacy and safety in practical application (Han *et al*., 2006). Nonetheless, the dearth of studies aimed at evaluating or testing the effect of ozone therapy on HDM allergens was concerning. It remained crucial to assess the treatment's ability to deactivate HDM allergens, regardless of its efficacy in killing the mites themselves, given that one of the major sources of HDM allergens was mite feces (Tovey *et al*., 1981). Hence, experiments like enzyme-linked immunosorbent assay (ELISA) and cell toxicity test using MTT assay could be utilized to assess allergen presence and cytotoxicity, respectively, providing valuable insights into the impact of ozone-treated and non-treated dust mite allergens on cell viability.

Moreover, ongoing advancements in nanotechnology and targeted drug delivery systems offered promising prospects for more effective management of HDM allergy. Nanotechnology enabled the design of innovative formulations and delivery methods for HDM eradication agents, potentially improving treatment outcomes. By encapsulating treatments within nanoscale carriers, such as nanoparticles, targeted delivery to HDM-infested sites could be achieved while minimizing adverse effects (Kashirina *et al*., 2015).

CONCLUSION

In conclusion, HDM allergy is a significant and urgent issue affecting people from all walks of life. It is crucial to develop effective strategies to mitigate the adverse effects of HDMs on human health and well-being. By integrating various treatment modalities, including physical methods, chemical treatments, and innovative technologies, we could strive towards more effective and precise management of HDM allergy.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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