CSIRO PUBLISHING

LAB REPORT
https://doi.org/10.1071/MA23053

Microbiology Australia

Mould contamination of dwellings after flooding

Heike G. Neumeister-Kemp[A,*], Lara M. Kemp[A] and Natalie M. Tijsen[A]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
Heike G. Neumeister-Kemp
R&D Department, Mycotec, 9 Water Street, Wentworthville, Sydney, NSW 2145, Australia
Email: heike@mould.com.au

Received: 28 October 2023
Accepted: 31 October 2023
Published: 17 November 2023

Cite this:
Neumeister-Kemp HG *et al.* (2023)
Microbiology Australia
44(4), 202–206. doi:10.1071/MA23053

ABSTRACT

Australia's sub-tropical coastline has been subjected to catastrophic flooding, congruent with a global trend of extreme weather events exacerbated by climate change. This study examined buildings post-flooding, to determine the impact of fungal contamination and evaluate remediation strategy success. Fungal species prevalence in association with wet building materials are outlined. Remediation methods found to be effective are highlighted. These findings support the necessity of establishing internationally recognised guidelines pertaining to mould contamination and remediation. This is particularly pertinent within the context of climate change. This research contributes to the scientific understanding of mycobiota in flood affected buildings, their health and safety implications and design of effective mitigation strategies.

Keywords: air cleaning, assurance program, climate change, climate disaster, education, exposure and health effects, extreme weather, flooding, mitigation (source control), mould, mycotoxin, policy, regulations, risk assessment, standards.

Background

Climate change has notably increased extreme weather events across the globe. Recently, Australia's sub-tropical coastline which is uniquely positioned on the country's Eastern-Shelf, has been subject to catastrophic atmospheric conditions, culminating in an extended 3-year La Niña phenomenon. This has led to several '1 in 100 years' floods due to anomalies referred to as 'rain-bombs' reflecting a global trend in unprecedented extreme weather events. Juxtaposed with each summer's prevailing bushfires, shock rainfall and mass flooding incidents into commercial and domestic buildings have devastated vast swaths of the country.[1] Many affected areas are highly remote and comprise suburban housing, roads, crops and central waterways engulfed in blackwater. This has rendered access inordinately difficult, with many buildings either partially or completely submerged for hours to weeks on end (Fig. 1). The high number of dwellings affected following from these extreme weather events often results in a delayed time-frame for the assessment and remediation of buildings.

There are many ways that water can ingress into a dwelling following a disaster; however, two pathways predominate. The first being rain or hail events affecting buildings from above, by roof egress, and from the sides by wall egress, or gutter overflow. Secondly, surface water from rivers or oversaturated ground – that is no longer able to absorb any additional rainfall – often overflows into buildings from below. A lesser known yet prolific secondary ingress pathway is caused by prolonged extremely high relative humidity. This typically occurs due to a lack of ventilation or climate control inside a building due to power outages, resulting in condensation build up. Additionally, in many buildings flooded from below and left closed, water migrated up through the air and walls to proliferate in the upper floors.

It is well known that blackwater from flooding events carries a multitude of waterborne microorganisms including bacteria and viruses.[2,3] It is lesser known that once water subsides and buildings begin to dry, another large group of microorganisms emerge. Fungi and mould rapidly colonise the surfaces and penetrate deep into buildings; subsequent human exposure to these contaminated environments has a host of well documented associated health risks.[1,4–7] Although bacteria and viruses require moisture to survive, fungal propagation remains viable long past the point that moisture has subsided.[8]

High humidity or direct water inundation leads to an elevated water activity (Aw) within building materials. Levels above 75% water activity in any given building material will enable mould proliferation. This surface mould will eventually become airborne,

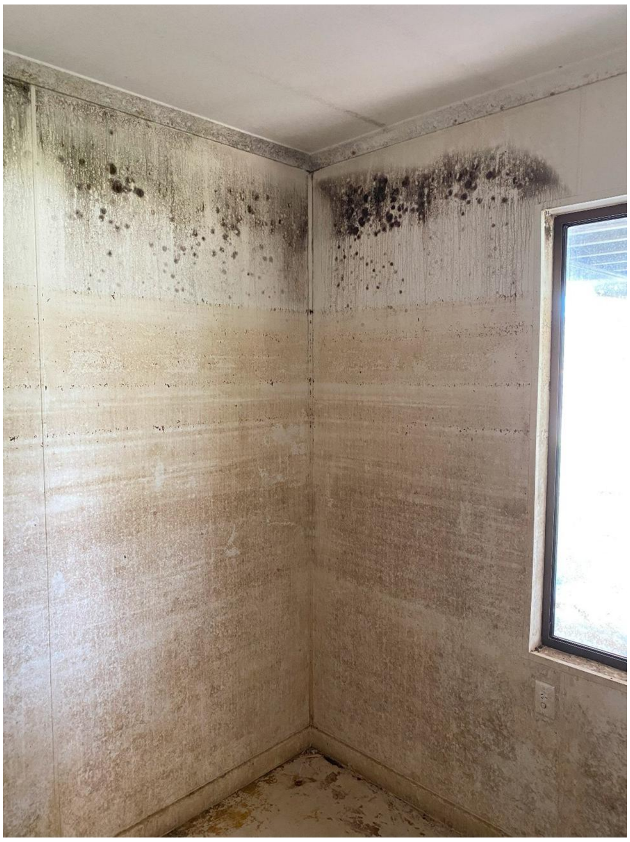

Fig. 1. Residential building wall mould growth above flood marked lines.

potentially cross contaminating all accessible areas of a built environment. Simultaneously, outdoor air concentrations of fungal spores rise, increasing the opportunity for mould to cross-colonise indoors. This is due to general post flood conditions, including high relative humidity, in combination with an extra nutritional load comprising of debris, vegetation, dead animals, wet surface soils and other displaced materials.

For the purpose of this study, only fungal contamination of buildings was considered. There is an increased risk of fungal infections after flooding, causing potential long term health effects in humans and animals such as respiratory and systemic infections. Additionally, poisoning from mycotoxins poses a notable risk, especially in already stressed or immunocompromised individuals, who may be suffering from displacement and psychological distress.[9]

Mycotoxicosis is a lesser-known term for poisoning associated with exposures to mycotoxins.[10] Mycotoxins are poisonous substances produced by fungi or mould as a natural defence mechanism against other fungi in the competition for nutrition. They can be toxic for humans when they are eaten, absorbed into the skin or inhaled.[11] Even a small amount of mycotoxin can be damaging to human or animal health, and in extreme cases causing death. They have been linked with the development of neurodivergent disease.[12] Mycotoxins have the potential for both acute and chronic health effects, through entering the blood stream and lymphatic system. Nausea, gastrointestinal disturbances and vomiting symptoms have been reported in relation to mycotoxin exposure.[11,13,14]

The fungal genera *Aspergillus* and *Penicillium* are often found in water damaged buildings wherein humans are primarily exposed to them. They have the ability to produce ochratoxin A (OTA), which is a nephrotoxin, immunotoxin and carcinogenic mycotoxin. This chemical is produced by moulds in both the *Aspergillus* and *Penicillium* genera.[15]

Citrinin (dihydrocitrinone, DHC) is a mycotoxin produced by the same group of fungi, *Aspergillus, Penicillium* and *Monascus*. Citrinin exposure can lead to nephropathy, due to its ability to increase permeability of mitochondrial membranes in the kidneys.[16] Studies have linked citrinin exposure to a suppression of the immune response, and gastrointestinal system.[17]

More common health problems associated with exposure to building moisture and subsequent biological agents, affect the allergenic, respiratory, and immune system responses in humans. Increased incidences of respiratory symptoms such as asthma[18] and allergies including hay fever, allergic rhinitis, sinusitis and eczema have been well documented.[13,14,19,20] In addition, negative effects on, and suppression of, the immune systems health, and resilience regularly occur.[21] Illness may result from a combination of factors present in water-damaged indoor environments, including, but not limited to, mould spores and hyphal fragments, mycotoxins, bacteria, bacterial endotoxins and cell-wall components.[4] The mechanisms of illness include inflammation, oxidative stress, toxicity, infection, allergy and irritant effects of exposure. These effects have been linked to a heightened risk to the respiratory health of children.[22,23]

According to the Institute of Medicine of the National Academies health effects can arise from exposure to mould by-products such as volatile and semi-volatile organic compounds, mycotoxins and other components.[24] Furthermore, substances produced by bacteria that grow in damp environments have been implicated in a range of biologic and health effects. These include inflammation of mucous membranes, respiratory effects, immunotoxicity, neurotoxicity, sensory irritation, skin toxicity and cancer-causing effects. There is evidence that some species of mould can lead to illnesses, such as hypersensitivity pneumonitis, allergic sinusitis, and allergic bronchopulmonary aspergillosis in susceptible individuals.[25]

Ritchie Shoemaker was the first to associate exposure to mould and water damaged buildings with Chronic Inflammatory Response Syndrome (CIRS). He demonstrated that the immune systems of individuals with certain genes, could not react appropriately to biotoxins as they would in healthy individuals.[26] A recent study found negative effects on contextual memory, increased pain sensitivity and anxiety-like behaviour in mice when exposed to moulds found in water damaged buildings.[27]

A recent parliament inquiry into biotoxin exposure by the Australian government, has shown a clear link between mould exposure and various symptoms, including CIRS.[28] Other studies on the long-term effects of mould and mycotoxin exposure suggest a link between mycotoxins and neurodegenerative diseases such as Alzheimer's Disease, Parkinson's Disease and Multiple Sclerosis.

As established, to avoid experiencing the negative health effects associated with mould exposure – as outlined in the literature – exposure to mould should be avoided. Therefore, after flooding events, when risk of mould exposure is heightened, appropriate assessments should be conducted to ensure the safety of individuals and buildings.

The authors of this paper were commissioned by insurers to 'roll out' an Insurance Assurance program and independently validate mould contamination and remediation efforts after flooding and rain bombs. In Declared Catastrophic ('CAT') events, such as 'CAT 202', which occurred in Townsville, Queensland, in 2019, and 'CAT 781', which occurred in the Murray–Darling River Basin, South Australia, several hundred thousand dwellings were simultaneously affected. Pre-inspecting every single dwelling prior to remediation was not possible, because of the sheer volume of buildings and a lack of infrastructure and resources. Therefore, a generic remediation and scope of works for each CAT event was established and issued to builders and restorers. This was based on, and factored in parameters, such as the nature of water inundation, its duration, and the relevant climatic zone.

Each dwelling is an individual case, affected by building materials, age, geography and response speed of restorers. As such, it was of outmost importance to establish whether the proposed generic scope of works was sufficient for the removal and mitigation of mould contamination at each building.

Post Remediation Verification (PRV) testing was conducted after a 'strip out' and subsequent remediation of dwellings, to ensure the efficacy of the nominated process. If the process was found to be ineffective or incomplete remediation was repeated based on the PRV results.

A final Clearance Testing (CLT) after reinstatement of the dwelling was conducted as legal protection for builders and remediators in addition to providing 'peace of mind' for owners and occupiers. The data from both the PRV and CLT was then used in the process of re-insuring dwellings that had been disaster affected.

Methods

A 3-part risk assessment for mould exposure was produced based on existing literature and practice, this included mould, moisture and relative humidity testing. Methods for cultural and non-cultural fungal air and surface sampling were used, to determine the number and speciation of mould present. Simultaneously a visual and moisture assessment was conducted and Temperature (°C), CO_2 levels (ppm) and relative humidity (% RH) were measured.

Results

Results from the fungal analysis showed that *Penicillium chrysogenum* and *Cladosporium cladosporioides* are the most common fungal species found in the air of dwellings after floods, followed by *Aspergillus versicolor* to a lesser degree.

The results demonstrated that *Chaetomium* spp., *Trichoderma* spp., *Acremonium* spp. and *Ulocladium* spp. are highly common on damp building materials after flooding.

Analyses revealed that associated mycobiota exist on different building materials, associations were found between:

(i) *Acremonium* spp., *Penicillium chrysogenum*, *Stachybotrys* spp. and *Ulocladium* spp. with plasterboard and wallpaper.
(ii) *Aureobasidium pullulans*, *Cladosporium herbarum*, *Trichoderma* spp. and yeasts with several types of wood (yellow–green tongue) and plywood.
(iii) *Aspergillus fumigatus*, *A. melleus*, *A. niger*, *A. ochraceus*, *Chaetomium* spp., *Mucor racemosus* and *M. spinosus* with concrete and other floor-related materials.

These results (Table 1) can be used to develop new and resistant building materials and relevant allergen extracts and to help focus research on relevant mycotoxins, microbial volatile organic compounds, and microparticles released into the indoor environment.

Congruent with the recommendations of both *The Australian Mould Guideline*[23] and *The Mould Workers Handbook*,[29] the consistent success of remediators is attributed to the physical agitation of surfaces by high-efficiency particulate-absorbing (HEPA) filter vacuuming with horsehair brushes and wet wiping with a microfibre cloth. Use of either naturally brewed vinegar, alcohol or bio-enzymes had demonstratable positive outcomes as opposed to bleach, chlorine, oils, biocides and various branded 'organic' products that are demonstrated to be ineffective. Additional factors contributing to success include air scrubbing with a minimum of seven air changes throughout the remediation process followed by a gaseous treatment with hydrogen peroxide. Methods such as encapsulation with glues or paints, dry-ice blasting, fogging or spraying with various substances consistently failed PRV testing.

Conclusions

It can be concluded that there exists an associated mycobiota for different building materials much like there exists an associated mycobiota on different food types. The results presented can provide assistance to the building industry in the development, production and usage of materials that are less susceptible to fungal growth. Utilising glass fibre instead of wallpaper for example or manufacturing materials that consist of a non-toxic, fungus- or water-resistant composition such as coating plasterboards against *Stachybotrys* spp., would aid in limiting fungal growth within building after flooding events or prolonged relative humidity in turn decreasing the likelihood of mould exposure-related illnesses from occurring. With the notion of extreme changes in the world's climate, standards and guidelines are necessary for the development and assurance of future building materials, infrastructure and remediation to be able to combat fungal growth, henceforth, there is a pressing need for an internationally accepted and recognised guidelines. Currently, the World Health Organization has guidelines regarding indoor air quality[21]; however, these are not easily applicable for Australian ecologies, therefore, standards for the remediation and assessment of mould pertaining specifically to Australia are needed.[29,30]

Table 1. Most common fungi found on contaminated building surfaces after flooding in Australia.

Acremonium sp.
Alternaria alternata
Ascomycetes
Aspergillus fumigatus
Aspergillus niger
Aspergillus flavus
Aspergillus restrictus
Aureobasidium sp.
Basidiomycetes
Botrytis sp.
Bipolaris sp.
Chaetomium sp.
Cladosporium cladosporioides
Curvularia sp.
Dreschlera sp.
Epicoccum sp.
Fusarium oxysporum
Fusarium solani
Geotrichum sp.
Monilia sp.
Monoascus spp.
Mucor spp.
Nigrospora sp.
Paecilomyces sp.
Penicillium corylophilum
Penicillium chrysogenum
Penicillium brevicompactum
Rhizopus sp.
Stachybotrys sp.
Stemphylium sp.
Sporobolomyces roseus
Trichoderma sp.
Ulocladium sp.
Yeast

The data obtained from this assurance program will form the base for research at the newly found RAC[1] Training Centre for Advanced Building Systems Against Airborne Infection Transmission at Queensland University of Technology (QUT) in Brisbane, Australia officially known as the THRIVE project.

References

1. Coulburn L, Miller W (2022) Prevalence, risk factors and impacts related to mould-affected housing: an Australian integrative review. *Int J Environ Res Public Health* **19**, 1854. doi:10.3390/ijerph19031854
2. Furtak K *et al.* (2020) Prevalence of unclassified bacteria in the soil bacterial community from floodplain meadows (fluvisols) under simulated flood conditions revealed by a metataxonomic approachss. *CATENA* **188**, 104448. doi:10.1016/j.catena.2019.104448
3. Masciopinto C *et al.* (2019) Human health risk assessment for the occurrence of enteric viruses in drinking water from wells: role of flood runoff injections. *Sci Total Environ* **666**, 559–571. doi:10.1016/j.scitotenv.2019.02.107
4. Andersen B *et al.* (2011) Associations between fungal species and water-damaged building materials. *Appl Environ Microbiol* **77**, 4180–4188. doi:10.1128/AEM.02513-10
5. Gravesen S *et al.* (1999) Microfungal contamination of damp buildings-examples of risk constructions and risk materials. *Environ Health Perspect* **107**, 505–508. doi:10.1289/ehp.99107s3505
6. Hyvärinen A *et al.* (2002) Fungi and actinobacteria in moisture-damaged building materials – concentrations and diversity. *Int Biodeterior Biodegradation* **49**, 27–37.
7. Kildesø J *et al.* (2003) Determination of fungal spore release from wet building materials. *Indoor Air* **13**, 148–155. doi:10.1034/j.1600-0668.2003.00172.x
8. Beuchat L R (1983) Influence of water activity on growth, metabolic activities and survival of yeasts and molds. *J Food Prot* **46**, 135–141. doi:10.4315/0362-028X-46.2.135
9. Polizzi V *et al.* (2009) Jem spotlight: fungi, mycotoxins and microbial volatile organic compounds in mouldy interiors from water-damaged buildings. *J Environ Monit* **11**, 1849–1858. doi:10.1039/b906856b
10. Rotter BA *et al.* (1996) Toxicology of deoxynivalenol (vomitoxin). *J Toxicol Environ Health* **48**, 1–34. doi:10.1080/009841096161447
11. Peraica M *et al.* (1999) Toxic effects of mycotoxins in humans. *Bull World Health Organ* **77**, 754–766.
12. Nguyen VTT *et al.* (2022) The role of mycotoxins in neurodegenerative diseases: current state of the art and future perspectives of research. *Biol Chem* **403**, 3–26. doi:10.1515/hsz-2021-0214
13. Gray M (2007) Molds and mycotoxins: beyond allergies and asthma. *Altern Ther Health Med* **13**, 146–152.
14. Gray MR *et al.* (2003) Mixed mold mycotoxicosis: immunological changes in humans following exposure in water-damaged buildings. *Arch Environ Health* **58**, 410–420. doi:10.1080/00039896.2003.11879142
15. Wang Y *et al.* (2016) Ochratoxin a producing fungi, biosynthetic pathway and regulatory mechanisms. *Toxins* **8**, 83. doi:10.3390/toxins8030083
16. Flajs D, Peraica M (2009) Toxicological properties of citrinin. *Arh Hig Rada Toksikol* **60**, 457–464. doi:10.2478/10004-1254-60-2009-1992
17. Gao Y *et al.* (2020) The compromised intestinal barrier induced by mycotoxins. *Toxins* **12**, 619. doi:10.3390/toxins12100619
18. Schütze N *et al.* (2010) Exposure to mycotoxins increases the allergic immune response in a murine asthma model. *Am J Respir Crit Care Med* **181**, 1188–1199. doi:10.1164/rccm.200909-1350OC
19. Hedayati MT *et al.* (2007) *Aspergillus flavus*: human pathogen, allergen and mycotoxin producer. *Microbiology* **153**, 1677–1692. doi:10.1099/mic.0.2007/007641-0
20. Holme J *et al.* (2010) Culturable mold in indoor air and its association with moisture-related problems and asthma and allergy among Swedish children. *Indoor Air* **20**, 329–340. doi:10.1111/j.1600-0668.2010.00658.x
21. World Health Organization (2009) WHO guidelines for indoor air quality: dampness and mould. https://www.who.int/publications/i/item/9789289041683
22. Garrett MH *et al.* (1998) Indoor airborne fungal spores, house dampness and associations with environmental factors and respiratory health in children. Clinical and experimental allergy. *Clin Exp Allergy* **28**, 459–467. doi:10.1046/j.1365-2222.1998.00255.x
23. Kemp PC *et al.* (2010) *Australian Mould Guideline*. Messenger Publishing.
24. Institute of Medicine of the National Academies (2004) *Damp Indoor Spaces and Health*. The National Academies Press, Washington, DC, USA. doi:10.17226/11011

[1]Royal Automobile Club of Western Australia.

25. New York State Department of Health (2010) *New York State Toxic Mold Task Force Report to the Governor and Legislature*. NYC Department of Health, New York, NY, USA.
26. Berndtson K (2013) *Chronic Inflammatory Response Syndrome: Overview, Diagnosis, and Treatment*. MultiMed, Park Ridge, IL, USA.
27. Harding CF *et al.* (2020) Mold inhalation causes innate immune activation, neural, cognitive, and emotional dysfunction. *Brain Behav Immun* **87**, 218–228. doi:10.1016/j.bbi.2019.11.006
28. Australian Government Department of Health and Aged Care (2020) Australian Government response to the House of Representatives Standing Committee on Health, Aged Care and Sport's report on the Inquiry into Biotoxin-related Illnesses in Australia. https://www.aph.gov.au/DocumentStore.ashx?id=8d78bafa-5f57-4f98-87b3-6b61859eb667
29. Kemp PC, Neumeister-Kemp HG (2010) *The Mould Worker's Handbook: A Practical Guide for Remediation*, 2nd edn. Enviro Trust.
30. Neumeister-Kemp HG *et al.* (2001) Alteration in indoor fungal levels via portable HEPA air filters in bedrooms of asthmatic children. *Mycoses* **44**, 244.

Data availability. Data can be made available on reasonable request.

Conflicts of interest. The authors declare that they have no conflicts of interest.

Declaration of Funding. This research did not receive any specific funding.

Author affiliation

[A]R&D Department, Mycotec, 9 Water Street, Wentworthville, Sydney, NSW 2145, Australia.

Biographies

Dr Heike Neumeister-Kemp is the principal mycologist, founder and CEO of Mycotec. Heike is world renowned as a leading expert in the field of Environmental Mycology. Her passion for education and human rights helped to found the Indoor-Air-Quality Industry in Australia. Affectionately known as the 'Mould Lady', she is personally responsible for saving the homes, hospital's and lives of countless people through her work.

Lara Kemp is a science journalist at Mycotec. Lara is an innovative communicator, dedicated to enhancing public understanding of science and technology in the modern world.

Natalie Tijsen is a Wildlife Ecologist with a BSc in Forensics. Natalie is a bright young scientist and new pioneer in the field of mycology. Her love of ecology and forensic background have combined to create the perfect forensic mycologist.