Ministry for Primary Industries
Manatū Ahu Matua

Import risk analysis: Phytosanitary Risks of Importing Phase III *Agaricus bisporus* Mushroom Compost from Northern Europe

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Cover photo: Incubating Phase III *Agaricus bisporus* Mushroom Compost

Photo credit: Dr. Michael Ormsby

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Import Risk Analysis: Phytosanitary Risks of Importing Phase III *Agaricus bisporus* Mushroom Compost from Northern Europe

Version 2

22nd March 2017

Approved for general release

Peter Thomson
Acting Director
Biosecurity Science and Risk Assessment
Ministry for Primary Industries

Version information

Version number	Comments	Date of release
1.0	Not expert reviewed, available for consultation only	14th December 2016
2.0	Updated information seed and fungal risks – seed heat tolerance and fungal world-wide distributions	22nd March 2017

New Zealand is a member of the World Trade Organisation and a signatory to the Agreement on the Application of Sanitary and Phytosanitary Measures ("The Agreement"). Under the Agreement, countries must base their measures on an International Standard or an assessment of the biological risks to plant, animal or human health.

This document provides a scientific analysis of the phytosanitary risks associated with Phase III Mushroom Compost from Northern Europe. It assesses the likelihood of entry, exposure, establishment and spread of phytosanitary pests in relation to imported Phase III *Agaricus bisporus* mushroom compost from Northern Europe and assesses the potential impacts of those organisms should they enter and establish in New Zealand. The document has been internally reviewed and is now released publically. An externally peer review will now be undertaken. Any significant new science information received that may alter the level of assessed risk or efficacy of the measures will be included in a revision of the analysis, and an updated version released.

Contributors to this risk analysis

The following people provided significant input into the development of this risk analysis:

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Contents

Page

Tables

Page

Figures

Page

Executive summary

A total of 187 different species or pest/disease complexes were identified from a literature review for phytosanitary-related organisms potentially associated with imported Phase 3 *Agaricus bisporus* mushroom compost from northern Europe. Only two organisms were selected for a full risk analysis given the extent of heating and processing undertaken during the production of Phase 3 *Agaricus bisporus* mushroom compost, much of which is designed to remove pest or disease organism contaminations. The selected organisms were:

1) Mushroom Virus X or MVX complex;
2) *Trichoderma aggressivum* f. *europaeum* Samuels & W. Gams.

The risk analysis identified that MVX and *T. aggressivum* f. *europaeum* should be considered a biosecurity risk to New Zealand on imported Phase 3 *Agaricus bisporus* mushroom compost from northern Europe.

The critical components of the mushroom compost production process necessary for the management of the identified risks are identified as follows:

- Mushroom spores and/or mycelium used in mushroom spawn production may be collected from cultures that have been indexed (tested) and found free of MVX and *T. aggressivum* f. *europaeum.*
- All mushroom compost and casing may be heated for a minimum of 65°C for 4 hours for MVX; or 60°C for 12 hours or 65°C for 4 hours for *T. aggressivum* f. *europaeum.* After heating the compost should be handled in a manner that prevents re-infestation and, once the Phase 3 mushroom compost has been produced, packed in non-absorbent sterile packaging and stored in areas free of host fungi of MVX and *T. aggressivum* f. *europaeum* spores or mycelium, or organic contaminants in general.
- All used containers and equipment associated with mushroom production that may accompany the Phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe may be cleaned of organic material and disinfected if non-absorbent or if absorbent heated for a minimum of 65°C for 8 hours.

Should MVX or *T. aggressivum* f. *europaeum* arrive in New Zealand in imported mushroom compost, the success of any measures in mushroom production facilities in New Zealand to ensure any imported contaminated compost does not result in the establishment of MVX or *T. aggressivum* f. *europaeum*, would be limited by the inadequacy of currently available hygiene and detection methods.

If a heat treatment is undertaken to ensure any mushroom compost is free of MVX and/or *T. aggressivum* f. *europaeum*, the treatment should involve operational conditions that ensure all (100% to core) of the mushroom substrate is subject to the minimum temperature requirement as verified by assessing the temperature profile throughout the compost pile (e.g. by measuring the coldest spot (e.g. the surface and/or the centre of a compost pile)).

1 Risk analysis background and process

1.1 Background

This risk analysis has been developed in response to the following request from the Plant Imports and Exports Group; Plant, Food & Environment Directorate.

An expert review of a draft Risk Management Proposal and import health standard (IHS) for phase 3 mushroom compost identified some questions in regards to phase 3 imports that will need to be considered before proposed import requirements can be finalised for public consultation. This import risk analysis has been drafted in response to the comments made by the expert reviewers.

1.2 Scope of this risk analysis

This risk analysis is limited to the phytosanitary risks associated with importing phase 3 *Agaricus bisporus* mushroom compost from northern Europe (e.g. exported from the Netherlands, but potentially sourced from nearby countries such as the UK, France, Germany etc.). Phase 3 mushroom compost for the purpose of this assessment is for growing common mushroom (*Agaricus bisporus*) only. It is considered to have been produced using a mixture of horse and/or chicken manure, straw (wheat (*Triticum aestivum*) and/or oat (*Avena sativa*)), gypsum and water, and has been inoculated with mushroom spawn (*Agaricus bisporus* mycelia and cereal grains).

This phytosanitary risk analysis uses a qualitative methodology. A full risk analysis has been completed on selected pests only. An analysis of the sanitary risks associated with importing phase 3 mushroom compost has already been completed by the New Zealand Ministry for Primary Industries (MPI)[1].

1.3 The risk analysis process

The following briefly describes the MPI process and methodology for undertaking import risk analyses against biosecurity risks. For a more detailed description of the process and methodology please refer to the Biosecurity New Zealand Risk Analysis Procedures (Version 1 12 April 2006) which is available on the MPI web site[2].

The risk analysis process leading to the final risk analysis document is summarised in Figure 1.

1.3.1 Commodity and pathway description

The first step is to describe the commodity and entry pathway of the commodity. This includes where necessary relevant information on:

- the country of origin, including characteristics like climate, relevant agricultural practices, phytosanitary system;
- pre-export processing and transport systems;
- export and transit conditions, including packaging, mode and method of shipping;
- nature and method of transport and storage on arrival in New Zealand;
- characteristics of New Zealand's climate, and relevant agricultural practices.

[1] MPI 2016 Rapid Risk Assessment: Mushroom substrate containing horse and poultry manure. New Zealand MPI.
[2] http://mpi.govt.nz/document-vault/2031

This information provides context for the assessment of the potential hazard organisms.

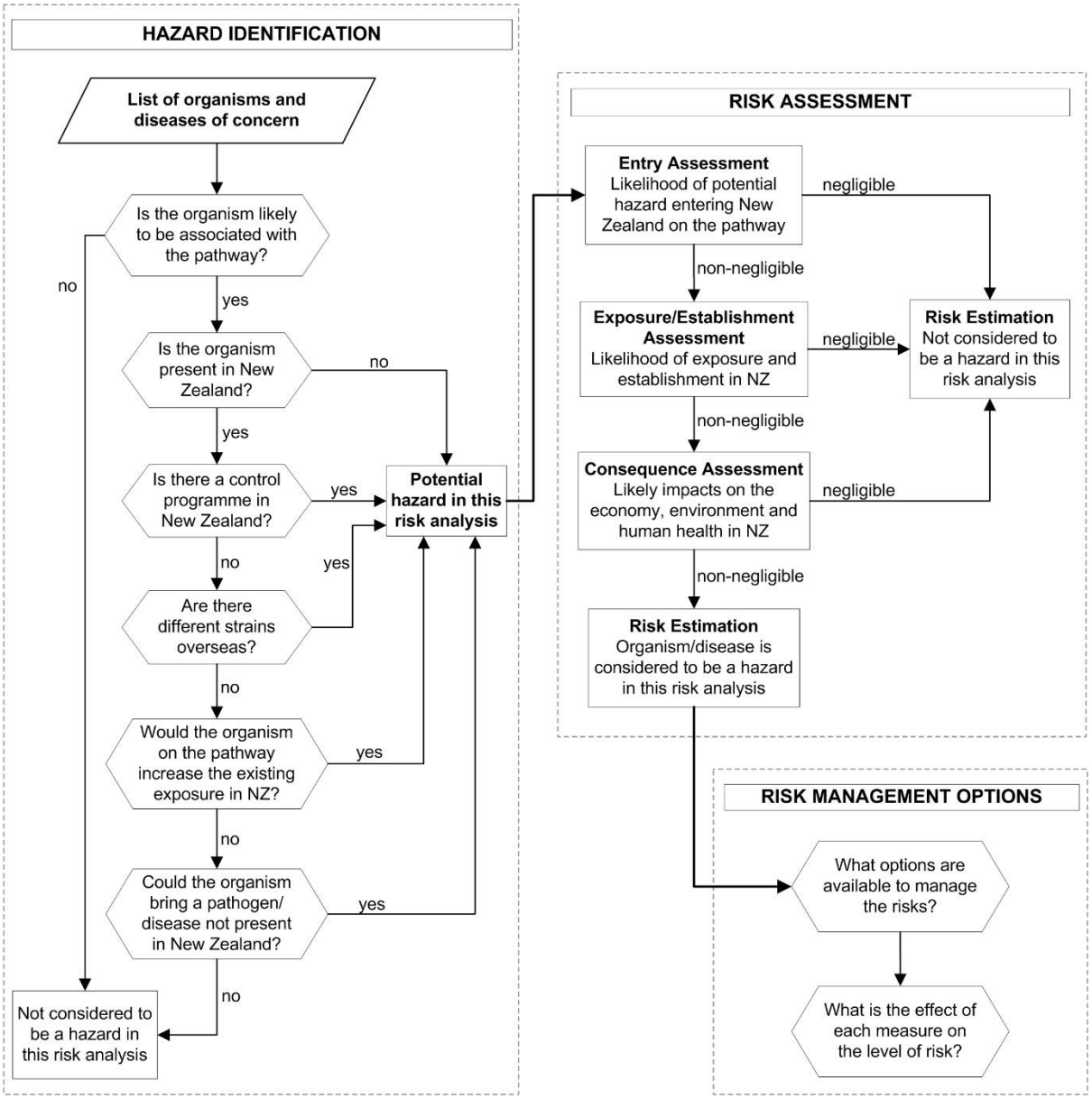


Figure 1: Diagrammatic representation of the risk analysis process

The process outlined in Figure 1 is further supported by the following:

1.4 Assessment of uncertainties

In this aspect of the risk analysis process the uncertainties and assumptions identified during the preceding hazard identification and risk assessment stages are summarised. An analysis of these uncertainties and assumptions can then be completed to identify which are critical to the outcomes of the risk analysis. Critical uncertainties or assumptions can then be considered for further research with the aim of reducing the uncertainty or removing the assumption.

Where there is significant uncertainty in the estimated risk, a precautionary approach to managing risk may be adopted. In these circumstances the measures should be reviewed as soon as additional information becomes available[3] and be consistent with other measures where equivalent uncertainties exist.

1.5 Management options

For each organism classified as a hazard, a risk management step is carried out, which identifies the options available for managing the risk. In addition to the options presented, unrestricted entry or prohibition may also be considered for each hazard. Recommendations for the appropriate phytosanitary measures to achieve the effective management of risks are not made in this document. These will be determined when an Import Health Standard (IHS) is drafted.

As obliged under Article 3.1 of the World Trade Organisation (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS Agreement), the measures adopted in IHSs will be based on international standards, guidelines and recommendations where they exist, except as otherwise provided for under Article 3.3 (where measures providing a higher level of protection than international standards can be applied if there is scientific justification, or if there is a level of protection that the member country considers is more appropriate following a risk assessment).

1.6 Review and consultation

Peer review is a fundamental component of a risk analysis to ensure the analysis is based on the most up to date and credible information available. Each analysis must be submitted to a peer review process involving recognised and relevant experts from New Zealand or overseas. The critique provided by the reviewers is reviewed and where appropriate, incorporated into the analysis. If suggestions arising from the critique are not adopted the rationale must be fully explained and documented.

Usually a risk analysis is published and released for public consultation once it has been peer reviewed and the critiques addressed it. In this instance the risk analysis will be peer reviewed at the same time as it is published and released for public consultation.

All submissions received from stakeholders will be analysed and compiled into a review of submissions. Either a document will be developed containing the results of the review or proposed modifications to the risk analysis or the risk analysis itself will be edited to comply with the proposed modifications.

[3] Article 5.7 of the SPS Agreement states that "a Member may provisionally adopt sanitary …. measures" and that "Members shall seek to obtain additional information …. within a reasonable period of time." Since the plural noun "Members" is used in reference to seeking additional information a co-operative arrangement is implied between the importing and exporting country. That is the onus is not just on the importing country to seek additional information.

2 Commodity and pathway description

Phase 3 mushroom compost for the purpose of this assessment is for growing common mushroom (*Agaricus bisporus*) only. It is considered to have been produced using a mixture of horse manure, chicken manure, straw (wheat (*Triticum aestivum*) and/or oat (*Avena sativa*)), gypsum and water, and has been inoculated with *Agaricus bisporus* mushroom spawn (*Agaricus bisporus* mycelia on sterilised cereal grains).

This assessment has focused on phase 3 mushroom compost imported from northern Europe only, although the conclusions reached may be applicable to other regions with a similar or reduce risk profile.

2.1 Commodity description

The commercial production of compost for growing the common mushroom (*Agaricus bisporus*) undergoes three main phases:

In **phase 1** the raw ingredients are mixed and composted at high temperatures (up to 80°C) for several days; the temperature and duration of compost depends on the individual manufacturer. In **phase 2** the product is then pasteurised (for example at 57-60°C for 6-10 hours) and conditioned at a lower temperature (for example 48°C for a further 2-3 days). The conditioned product is called 'phase 2 medium'[4].

After conditioning, phase 2 medium is inoculated with mushroom spawn and incubated at around 25°C for approximately two weeks. During this time the mushroom mycelium spreads throughout the growing medium. This colonised product is considered to be the **phase 3** mushroom compost. A mushroom crop can be grown directly from phase 3 medium after a peat-based casing is added to induce production of the edible fruiting bodies (mushrooms). Alternatively, phase 3 medium can be chilled to around -2°C and held until required; it is the chilled product that is being assessed under this import risk analysis.

Rynk & Richard (2001) list five main categories of composting systems:

- **I.** turned windrows;
- **II.** passively aerated static piles;
- **III.** forced aerated static piles;
- **IV.** combined turned and forced aerated windrows;
- **V.** in-vessel systems (horizontal agitated beds, aerated containers or 'tunnels', aerated agitated containers, silo or tower reactors).

Commercial methods for preparing Phase 1 mushroom compost consists mainly of turned windrows (category I. as per Rynk & Richard 2001) or in-vessel systems (category IV. or V. as per Rynk & Richard 2001) which then go through a pasteurisation and conditioning process in an enclosed heating chamber to produce Phase 2 mushroom compost.

A pictorial description of a generalised mushroom compost production process is provided in *Figure 2* below.

4 https://www.youtube.com/watch?v=IZOTwYxRaCQ

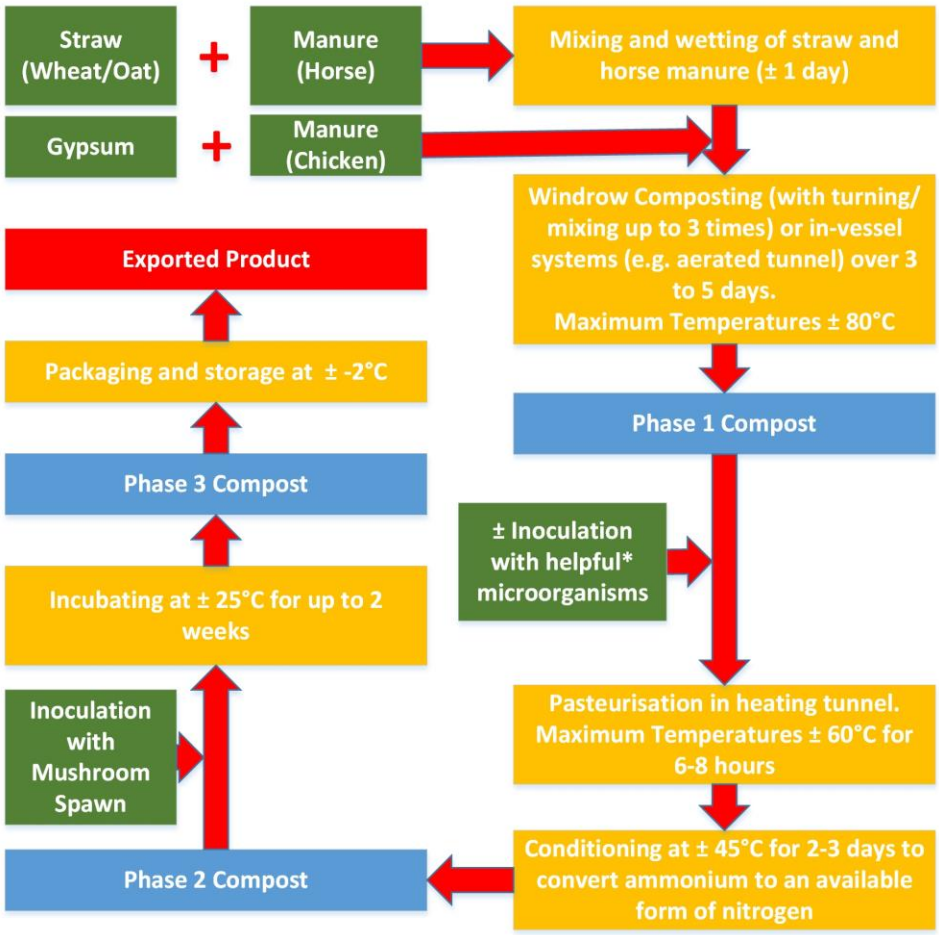


Figure 2: Generalised commercial process to produce phase 3 mushroom compost

* Helpful microorganisms are those that enable the pasteurisation and conditioning processes but are not pests of mushrooms.

2.2 Pathway description

Phase 3 medium is packaged in plastic wrapping and chilled to around -2°C until required. The chilled and packaged phase 3 medium is shipped to New Zealand by sea in containers, taking around 3 or so weeks before arriving in New Zealand. Warming of the compost to either ambient temperatures, or temperatures appropriate for mushroom cultivation, occurs on removal of the packages from the containers when delivered to the mushroom production facility in New Zealand.

2.3 The New Zealand mushroom industry

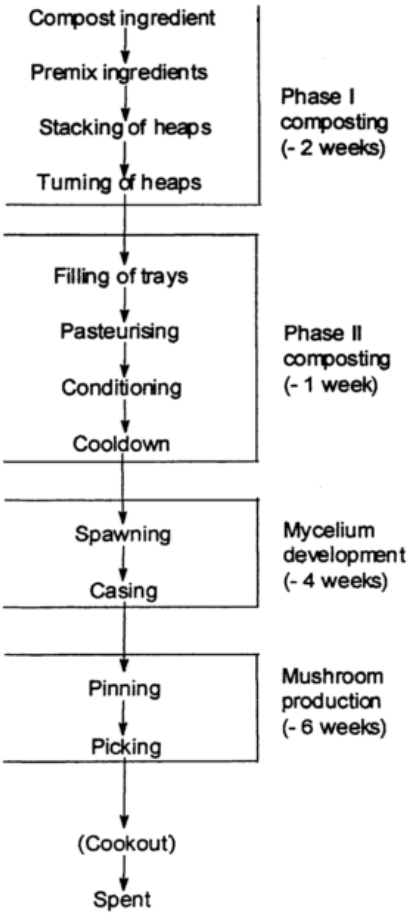
Mushrooms of the genus *Agaricus* have been cultivated worldwide for consumption since the 18th century (O'Brien 2012). Today *Agaricus bisporus*, the white button mushroom, is the most commonly cultivated mushroom in Europe, North America (O'Brien 2012) and New Zealand.

The New Zealand mushroom industry is based largely on different strains of the button mushroom *Agaricus bisporus*, with annual production of around 8,500 tonnes in 2015 (Fresh Facts 2015). New Zealand is a net exporter of mushrooms, mainly fresh white buttons and Swiss browns to Japan, Australia, and Southeast Asia. Most imports are dried or canned shiitake, oyster, and enokitake (Buchanan & Barnes 2002).

Commercial *Agaricus* cultivation in New Zealand began in the 1930s, flourishing in the 1960s with over 80 farms, many small, and sometimes growing in containers such as old banana boxes. Most of these farms have disappeared and less than a dozen significant farms remain. Mushroom production is located in semi-urban areas in both main islands where efficient transport links provide access to major centres of population. Large and mid-range white hybrids are predominantly grown, as well as pure brown strains and *A. bitorquis* (Buchanan & Barnes 2002).

New Zealand mushroom farms traditionally produced their own compost. Smaller farms produced compost conventionally: materials are mixed and formed into rows that are mechanically turned during 3 weeks of composting. Larger farms have installed aerated bunkers, in some cases as a result of odour complaints, or as a response to environmental legislation. Some of the bunkers are fully enclosed, and others have been sited well away from residential areas (Buchanan & Barnes 2002).

Mushroom production is a multi-step process (see figure to right). The first 2 phases involve the production of mushroom substrate from raw materials by biological composting processes. The substrate and casing is colonised by *Agaricus bisporus* mycelium in subsequent phases, then fruiting body formation is induced and mushrooms are harvested. Each of these steps is carefully controlled to maximise mushroom yield and quality and to minimise the opportunity for contamination with unwanted micro-organisms (O'Brien 2012).



Casing soil is a vital component of the mushroom production system, fruiting bodies cannot be induced to form without the addition of casing (O'Brien 2012). The role of the casing layer is three-fold, it must (O'Brien 2012):

- absorb and hold moisture, increasing the level of water available for the formation of fruiting bodies and preventing damage cause by drying out of the substrate;
- have a consistency which facilitates penetration of mycelial strands which supply nutrients and water to fruiting bodies from the substrate; and
- contain the microbial content necessary to induce the formation of fruiting bodies.

Fruiting bodies (edible mushrooms) first appear after about two weeks and are harvested. At about 7 day intervals after this, further flushes of fruiting bodies occur and are re-harvested. Growers usually allow a crop to produce two or three flushes after which it, and the cropping house, is cleaned for the next batch (Woodhall *et al*. 2009).

2.4 References for Chapter 2

Buchanan & Barnes (2002) The Mushroom Industry in New Zealand. Accessed October 2016: http://www.isms.biz/articles/the-mushroom-industry-in-new-zealand/

FreshFacts (2015) New Zealand horticulture facts and figures. The New Zealand Institute for Plant & Food Research Ltd.

O'Brien M. (2012) Molecular and epidemiological studies of *Trichoderma aggressivum* f. *europaeum*. PhD Thesis from the National University of Ireland, Maynooth: pp 210

Rynk R., Richard T.L. (2001) Commercial compost production systems. In: Stoffella P.J., Kahn B.A., eds. Compost Utilization in Horticultural Cropping Systems. Boca Raton, FL, USA:Lewis Publishers, 51–94.

Woodhall J.W., Smith J.E., Mills P.R., Sansford C.E. (2009) A UK commodity pest risk analysis for the cultivated mushroom, *Agaricus bisporus*. CSL/Warwick HRI, CSL Registered File No. PPP 12011A. pp 59.

3 Hazard identification

There are two groups of phytosanitary pests (seeds, mites, insects and micro-organisms (pathogens/saprophytic competitors)) that could potentially be associated with the movement of mushroom compost internationally: pests of mushrooms, and pests associated with the ingredients (e.g. straw) used to produce the compost. A list of the potential hazards associated with phase 3 mushroom compost is provided in the Appendix (***Table 1***) along with their hazard status. A short assessment is provided for each of those considered to be a potential hazard on this mushroom compost pathway (namely phase 3 mushroom compost from northern Europe).

From the results of the literature review for associated organisms provided in the Appendix, 187 different species or pest/disease complexes were identified. Within those 187 organisms or diseases:

- 12 were bacteria recorded as pathogens of mushrooms;
- 75 were fungi or fungi-like, of which 56 were recorded as mushroom competitors on compost (fungal saprophytes) and 19 as pathogens of mushrooms;
- 13 were insects, most of which were recorded as infesting the compost but some were also recorded as feeding directly on the mushroom mycelia;
- 17 were mites (Acarina), most of which were recorded as infesting the compost or as predatory (on other mites or arthropods), but some were also recorded as feeding on mushroom mycelia;
- 46 were nematodes, or which 18 were recorded as infesting the compost (saprophytic) while 28 were recorded as being mycophagous (fungal feeding);
- 1 slime mould was recorded as both a saprophyte on the compost and mycophagous (fungal feeding); and
- 23 viruses or virus complexes were recorded as pathogens of mushrooms.

Given the extent of the heating and processing undertaken during the production of phase 3 mushroom compost (see Section 4.1.4), much of which is designed to remove pest or disease organism contaminations, only two organisms of particular economic significance were selected for a full risk analysis:

a. Mushroom Virus X or MVX complex (see section *5.1*)

b. *Trichoderma aggressivum* f. *europaeum* Samuels & W. Gams (see section *5.2*)

All other organisms listed as being potential hazards associated with phase 3 mushroom compost (see the Appendix) are either expected to be managed by standard production practices (see Section 4) or are unlikely to cause substantive impacts in New Zealand (see the Appendix). Measures appropriate to the management of the biosecurity risks of the mushroom virus or *Trichoderma* species are also expected to manage the biosecurity risks presented by any of the other potential hazards. Details of these assumptions and an analysis of the expected management of pests other than the mushroom virus or *Trichoderma* species are provided in Section 4 of this assessment.

4 Overview of potential risk management options

4.1 Introduction

This chapter provides some general information about options that may be available to manage any risks that are considered of sufficient concern to require mitigation. As the nature and strength of any measures will need to reflect the nature and extent of the identified risks, actual mitigation options will be discussed within the risk management sections of each hazard risk analysis chapter.

Measures may be considered by themselves or in combination with other measures as part of a systems approach to mitigate risk.

4.1.1 Pest-free areas (PFAs)

The International Standards for Phytosanitary Measures (ISPM) 4 (*Requirements for the establishment of pest free areas*[5]) describes the requirements for the establishment and use of PFAs as a risk management option for meeting phytosanitary requirements for the import of plants or plant products. The standard identifies three main components or stages that must be considered in the establishment and subsequent maintenance of a PFA:

- Systems to establish freedom (through surveillance/surveys);
- Phytosanitary measures to maintain freedom (through pest lists/import requirements/product movement restrictions); and
- Checks to verify freedom has been maintained (through inspection/notification of pest occurrence/monitoring surveys).

Normally PFA status is based on verification from specific surveys such as an official delimiting or detection survey. It is accepted internationally that organisms or diseases that have never been detected in, or that have been detected and eradicated from, an area should not be considered present in an area if there has been sufficient opportunity for them to have been detected.

When sufficient information is available to support a PFA declaration, this measure is usually considered to provide a very high level of protection.

4.1.2 Pest free place of production (PFPP)

The ISPM 10 (*Requirements for the establishment of pest free places of production and pest free production sites*[6]) describes the requirements for the establishment and use of pest free places of production as a risk management option for meeting phytosanitary requirements for the import of plants or plant products. A pest free place of production is defined in the standard as a "place of production in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained for a defined period". Pest freedom is established by surveys and/or growing season inspections and maintained as necessary by other systems to prevent the entry of the pest into the place of production.

When sufficient information is available to support a PFPP declaration, this measure is usually considered to provide a high level of protection depending on the epidemiological characteristics of the organism or disease in question.

[5] https://www.ippc.int/en/publications/614/
[6] https://www.ippc.int/en/publications/610/

4.1.3 Sampling and testing or visual inspection

The purpose of any inspections is to determine whether there are viable organisms associated with the commodity; to gauge the efficacy of any risk management measures that have been applied, and; to provide an opportunity for additional remedial measures such as commodity treatment, re-shipment or destruction. The sampling regime depends on the level of confidence required for the absence of a particular organism, the detectability of the organism and the homogeneity of distribution of the organism within the consignment (ISPM 31[7]). Detectability will be considered in relation to individual organisms discussed in chapter 5.

Sampling can occur at multiple points during the compost production process, from compost ingredients before they are added or once the compost has been mixed either before or after heating or incubation. If sampling for visual (optical) detection, a delay of more than 24 hours after treatment (heating) would be required to ensure sufficient growth or reproduction of the target organism occurs. Sampling for testing can occur at any time although a delay after treatment would improve test sensitivity.

4.1.4 Heating that occurs within the commercial mushroom compost production process

The following analysis of the efficacy of heat as a treatment for pests in mushroom compost is based on those pests listed in the Appendix and any seeds that may be present.

Composting is a form of waste stabilization that requires special conditions, particularly of moisture and aeration, to yield temperatures conducive to thermophiles (Hoitink & Fahy 1986). The process, which is predominantly aerobic, involves both thermophilic (heat-tolerant) and mesophilic (warm-tolerant) microorganisms. Basically, the process can be divided into three phases:

- an initial phase of 1-2 days, during which temperatures rise and readily degradable compounds are decomposed;
- a thermophilic phase, possibly lasting months, during which (particularly in wood wastes) mainly cellulose is degraded; and
- curing or stabilization, a period when temperatures decline, decomposition rates decrease, and mesophilic microorganisms recolonize the compost (Hoitink & Fahy 1986).

Thermophilic bacteria, particularly *Bacillus* spp., appear to dominate the early phase of high activity, but thermophilic actinomycetes (fungi-like bacteria) predominate thereafter (Hoitink & Fahy 1986). The main by-products of "aerobic" composting are ammonia, carbon dioxide, water, and heat.

Even in the most highly aerated system anaerobic metabolism occurs in microhabitats, particularly early in the process. Metabolic end products of anaerobic composting are methane, carbon dioxide, and numerous intermediates, such as low molecular weight organic acids and various alcohols. The anaerobic composting process has a high odour potential (Hoitink & Fahy 1986).

Eradication of seeds, insects and/or pathogens (pests) from organic wastes during composting may be due to:

- high-temperature exposure;
- release of toxic products during or after the self-heating process; and
- microbial antagonism in the sub-lethal outer temperature zones of piles.

[7] https://www.ippc.int/en/publications/588/

Therefore factors other than heat, such as antibiotics and ammonia, may destroy such pests during composting. Even so, variability in concentrations of these factors and their effects during composting are such that it is essential to rely on temperature-time exposure for destruction (Hoitink & Fahy 1986). It should also be noted that as the intended purpose of the compost is for fungal growth (mushroom growing), the excessive presence of microbiotic antagonists or toxic products in the final product would be counter-productive.

In the preparation of mushroom compost the process is divided into three phases:

1. Phase 1 is the windrow or in-vessel period of composting, where temperatures may reach 80°C or more with the compost being turned several times and/or actively aerated over a 3-5 day period;
2. Phase 2 is the pasteurisation phase, where the compost is heated[8] in a chamber to around 60°C for several hours (6-10 hours), followed by a conditioning phase, where the compost is cooled to around 48°C for a week to remove free ammonia;
3. Phase 3 is when the compost is seeded with the mushroom spawn in preparation for production, and incubated for around 2 weeks at around 25°C. Seeding involves the mixing of the compost with the mushroom starter culture (spawn), which is the mushroom mycelia growing on some type of cereal grain or other seed.

4.1.4.1 *Heating consistency under composting conditions*

Compost is heated through both microbiological and chemical activity, with the temperature regulated aerobically through the strength of airflow, with stronger flow reducing temperatures. In some circumstances temperatures may need to be moderated through the heating or cooling of the airflow or the addition of water (at ambient temperatures) (MFE 2007). Increases in compost heating occurs when the proliferating mesophilic microorganisms within the composting material generate heat at a rate exceeding its loss to the surrounds, resulting in temperature increases when sufficient insulating mass exists to allow heat retention (Joshua *et al*. 1998). If insufficient oxygen is supplied to windrows, the centre of the mass will soon become anaerobic and less heat will be generated (Joshua *et al*. 1998).

As composting begins, temperature increase occurs throughout the composting mass and the well-insulated regions of the inner zones of the mass pass through the mesophilic/thermophilic boundary, which is in the range of 44°C to 52°C. Temperatures above 60°C will begin to impact on the activity of the microbial community and above this temperature activity declines as the thermophilic optimum is surpassed. Ultimately, the temperature may reach 82°C at which stage the biological community is severely impeded (Joshua *et al*. 1998).

Bollen *et al*. (1989) confirmed the relative tolerances of the fungi found in composting windrow trials, and determined that the compost heating period (up to 10 weeks) where temperatures rose to 70°C was the lethal phase. They noted that their conclusions on sanitation of crop residues by composting do not apply to the material at the surface.

Yuen & Raabe (1984) looked at the eradication of plant pathogens from windrow compost and found that 70°C temperatures in the centre of the compost pile were successful, however the compost had to be turned every 2 to 3 days to ensure adequate exposure to these temperatures. The need to turn windrow compost piles to ensure temperatures reached sufficient levels was further demonstrated by Downer *et al*. (2008).

Standards for compost sanitization have been developed in the USA by the Composting Council of the United States (Leege & Thompson 1997), in the UK jointly by the Waste and

[8] Heating is from the activity of microbes with air circulation, but may be supplemented by heated air to ensure even heating occurs.

Resources Action Programme (WRAP) and the Composting Association (Anon 2002), as well as in several other European countries (Stentiford 1996). These specify minimum compost temperatures of 55–65°C for periods of 3–14 days depending on the composting system (turned windrow, in-vessel, static aerated piles) (Noble & Roberts 2003). A risk assessment of composting to dispose of catering waste containing meat recommended a minimum composting temperature of 60°C for 2 days (Gale 2002). Based on survival probabilities, this report also recommended that windrows should be turned at least three times during the composting.

Christensen *et al*. (2002) recommend even more stringent sanitary requirements: 70°C for 2 days or 65°C for 4 days, with at least five turnings in windrow systems.

Probability studies by Gale (2002) indicated that the risk of pathogen survival in windrow systems is small, provided the windrows achieve the stipulated average temperatures and are turned at least the specified minimum number of times. They noted that of greater concern for pathogen survival are the cool zones in static and in-vessel composting systems where there is no or little turning. Data sets analysed by Gale (2002) indicate that, of the composting green waste in turned-windrow and in-vessel systems, at least 20 and 5%, respectively, is below 55°C at any particular time.

Wickuk *et al.* (2011) noted that as well as being composed of the correct nutrients and structural material, compost piles must be of appropriate dimensions to avoid excessive compaction in the centre or heat loss at the sides, which could create zones of reduced aeration and low temperatures.

Windrow composting systems

Nobel & Roberts (2004) reviewed the literature on the composting conditions required to eradicate fungi, bacteria and nematodes from infested plant material.

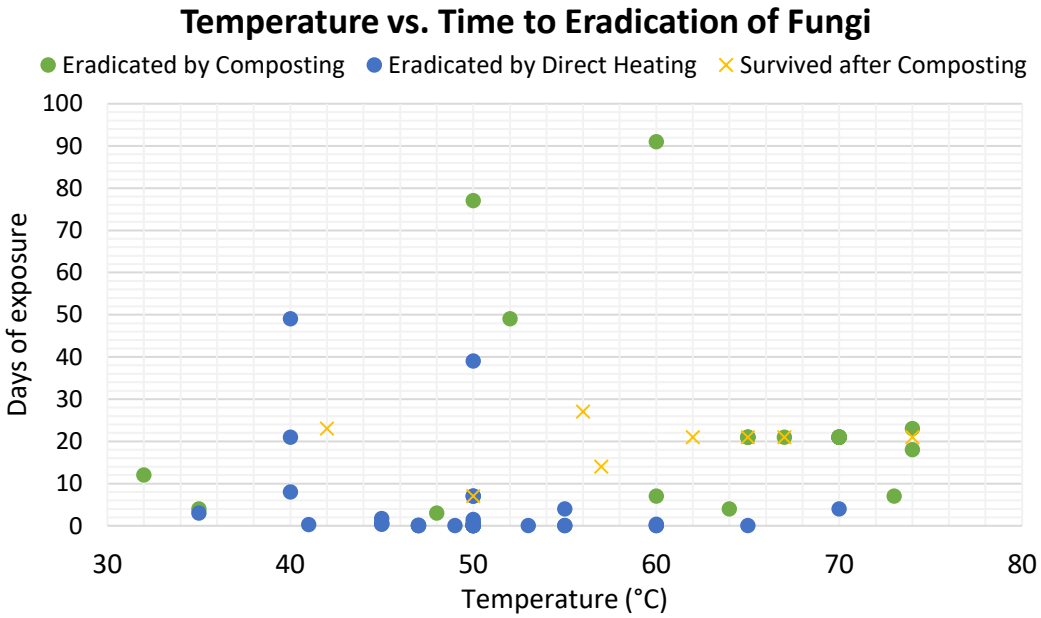


Figure 3: The time taken for fungi to be eradicated from composting or direct heating systems at different temperature levels (data from Nobel & Roberts 2004).

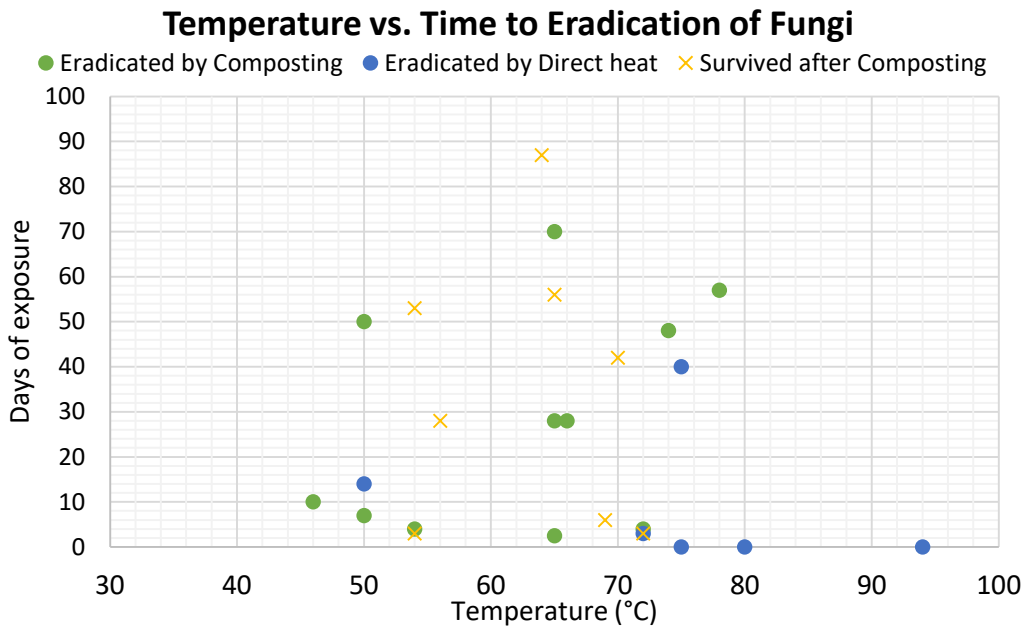


Figure 4: The time taken for viruses to be eradicated from composting or direct heating systems at different temperature levels (data from Nobel & Roberts 2004).

They found that under windrow composting conditions (turned piles), fungi (*Figure 3*) and viruses (*Figure 4*) required considerably more time to be eradicated at equivalent temperatures than under more direct or consistent heating systems.

Joshua *et al*. (1998) completed a study to investigate the temperature and oxygen profiles in a green organic windrow processing system. The aim of the study was to characterize the effectiveness of a passive ventilation system in windrowed plant residues for the control of temperature and oxygen concentrations. Measurements were taken of the green organic material within 30 different stockpiles prior to processing and within 30 commercial windrows throughout processing. The highest and lowest temperatures recorded in windrowed processing material were 72.8°C and 17.6°C respectively. Predominantly thermophilic conditions were maintained in the windrows throughout processing and virtually all material was subjected to 55°C for three days (Joshua *et al*. 1998).

Windrow composting systems are unlikely to achieve adequate sterilisation from pathogenic organisms in the phase 1 mushroom compost. To achieve sterilisation in a more predictable and reasonable time frame, more controlled composting conditions or direct heating methods should be used to ensure all of the compost achieves the target temperatures.

In-vessel composting systems

Under in-vessel composting systems, compost temperatures can be moderated more effectively to achieve target temperatures more evenly across the compost pile. *Figure 5* contains a measured temperature chart from an in-vessel composting system in The Netherlands (pers. comm.). What is noticeable is the even temperatures achieved over the range of depths within the compost over extended periods (75-80°C for over the last 30 hours). As noted above, Gale (2002) stated that the cool zones in static and in-vessel composting systems where there is no or little turning result in an estimated 5% of the compost remaining below 55°C at any particular time. If these cool zones are created during in-vessel composting, they would allow for pathogen survival and subsequent re-infestation of the compost on mixing.

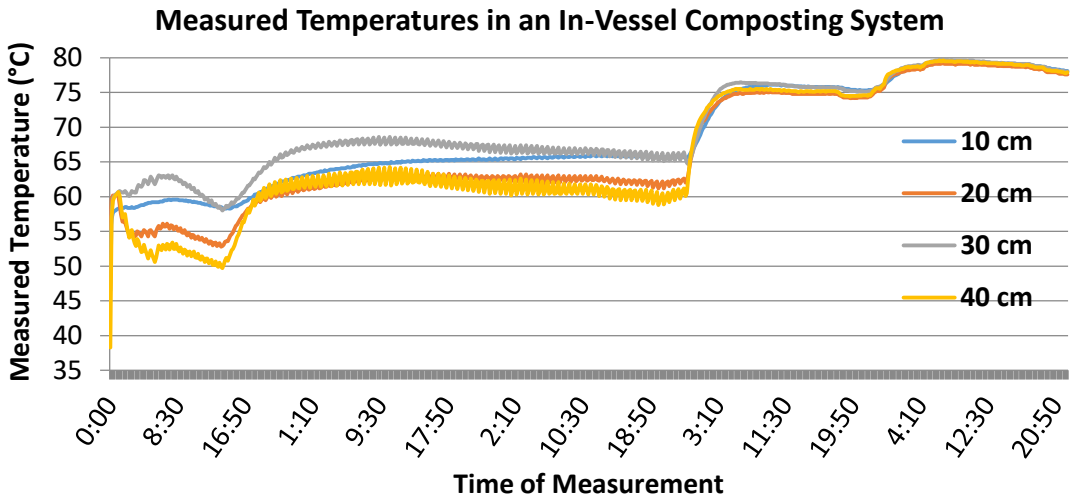


Figure 5: An example of the compost temperatures measured at various depths of in an in-vessel composting system (pers. comm.).

Compost that is effectively treated for 10 or more hours at temperatures exceeding 75°C will need to be re-seeded with the harmless microorganisms required to achieve later conditioning of the compost in phase 2.

Pasteurisation systems

The stated purpose of the pasteurisation process, which occurs after phase 1 composting in turned-windrow and in-vessel systems, is to attempt to sterilise the compost of pathogens or saprophytes that may reduce later mushroom production. It is therefore expected (or assumed) that these pathogens will either survive the earlier (phase 1) composting process or will infest the completed phase 1 compost.

To ensure the harmless thermophilic microorganisms required for successful conditioning are not killed off during pasteurisation, temperatures in the compost should not exceed around 60-62°C. Temperatures lower than 55°C are likely to allow pathogens to survive in quantities detrimental to later mushroom production. Pasteurisation is therefore undertaken within enclosed containers using forced aeration (fans) and may include the addition of heating (e.g. heated air) to facilitate even and consistent heating throughout the compost.

4.1.4.2 *Heating requirements for eradication of fungi, bacteria, viruses and nematodes*

As many important micro-organisms can re-populate the compost from a small infestation, to achieve adequate protection for biosecurity purposes the expected outcome of any treatment should be either the eradication of pests or sterilisation of the compost, or rendering the compost an unsuitable substrate for the pest or its host. Some viruses in particular may be host-dependent, and killing the host (such as a fungus) would also remove the virus from the compost.

Bollen (1969) exposed a range of soil fungi and bacteria to a range of temperatures for a 30 minute exposure period and found that bacteria (including actinomycetes) were more tolerant to heat than fungi, and saprophytic fungi usually more tolerant to heat than pathogenic fungi. None of the pathogenic fungi tested survived a heat treatment of 60°C for 30 minutes, whereas bacteria and some saprophytic fungi survived the highest temperature tested (90°C) for the 30 minutes. Bollen (1969) noted that the level of tolerance to heat was species specific.

Few data are available on survival of the most heat-resistant fungal pathogens, such as *forma specialis* of *Fusarium oxysporum*. Viruses with high inactivation temperatures, e.g. Tomato

Mosaic Virus, also may be difficult to eradicate from infested crop residues (Hoitink & Fahy 1986). Most specialised plant pathogens are killed by at least a 30 minute exposure to 55°C (Hoitink & Fahy 1986) and would not be expected to survive the phase 2 pasteurisation process (60°C for 6 or more hours).

In measuring fungal tolerances to heat under more controlled direct-heating conditions, Ramsfield *et al*. (2008) determined that all of the fungi tested were killed at or below 66°C after 120 minutes (see *Figure 6*).

From these results it can be surmised that under composting systems where even heating occurs throughout the compost pile, temperatures as low as 65°C for 4 or more hours should be considered appropriate for all but the most thermophilic fungi. For fungi that are directly pathogenic to plants, four or more hours at temperatures exceeding 60°C should be considered appropriate.

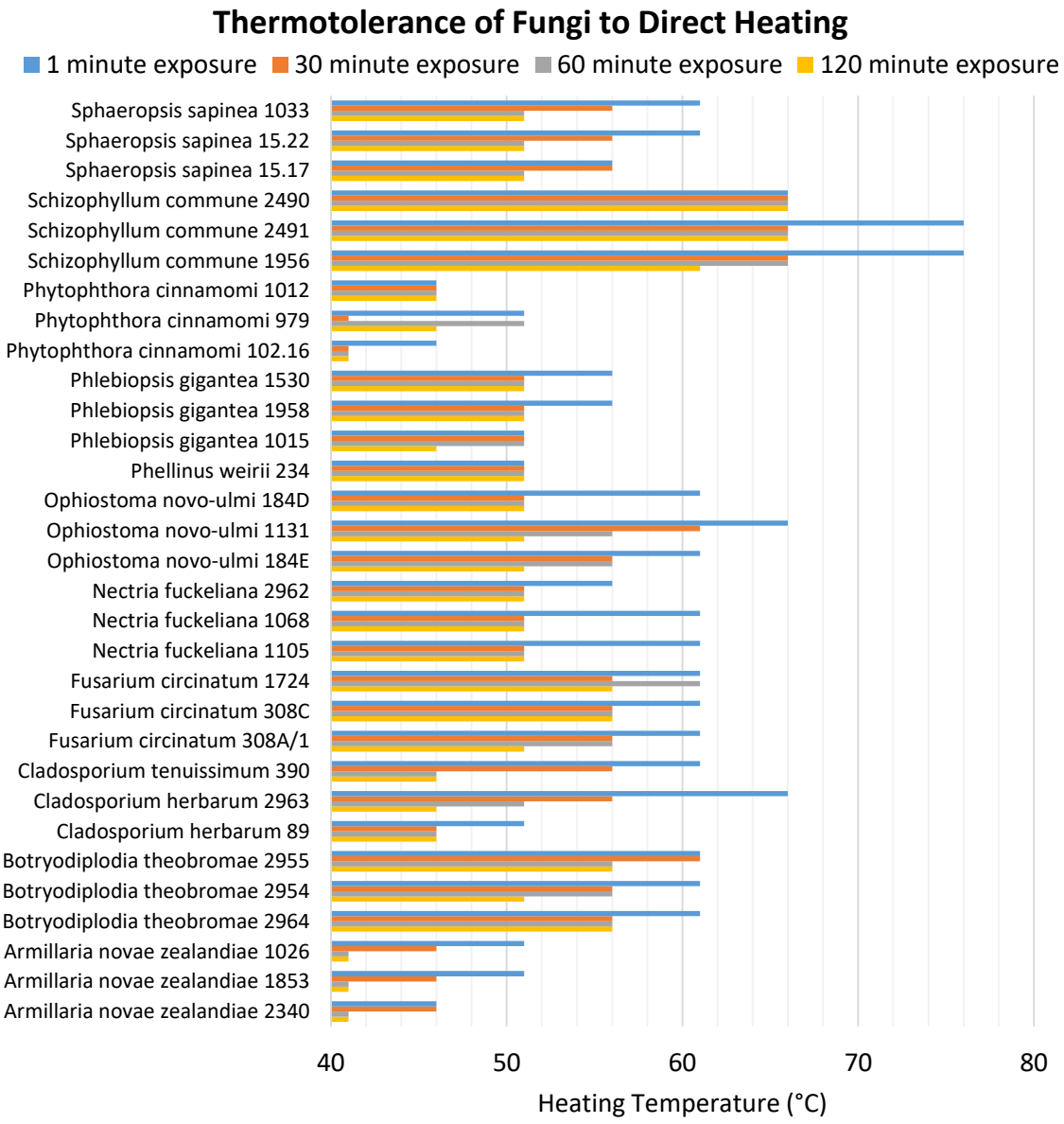


Figure 6: The temperatures required for fungi isolates to be eradicated from direct heating systems over different time intervals (data from Ramsfield *et al*. 2008).

4.1.4.3 *Heating requirements for eradication of plant seeds*

Unlike microorganisms associated with composts, plant seeds cannot propagate themselves within the compost and as such the entire compost production process can, as a system, play some role in the reduction and potential eradication of any seed contamination.

Larney & Blackshaw (2003) investigated the effect of the windrow composting process on the viability of 14 common species of pasture weed seed over an extended period. They found that the combination of heat, moisture and potentially other factors resulted in weed seed eradication (no germination) over a 14 day period. The seed mortality was not correlated to heat (40-60°C) alone, and they hypothesised that as dry seed was more heat-tolerant than wet seed, the presence of moisture increased seed mortality.

Zaborski (2015) noted that several factors contribute to weed seed mortality during windrow composting, the most important being the interaction between weed species, temperature, time, and moisture. Dahlquist *et al.* (2007) estimated that three of the six weed species they examined under controlled laboratory conditions to simulate soil solarisation (e.g. moist substrate) were unaffected by temperatures of 42°C, but at least 90% of the seeds of all six species were killed after less than three hours at 60°C (see *Figure 7*).

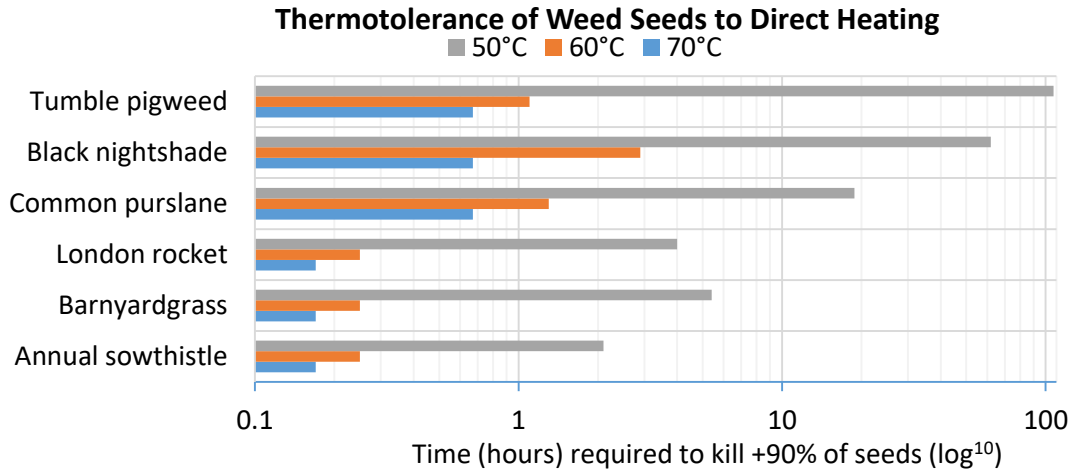


Figure 7: The time intervals required for weed seeds to be rendered non-viable from moist direct heating systems over different temperatures (data from Dahlquist *et al*. 2007).

The potential ability of a particularly heat-tolerant weed species, namely Velvetleaf (*Abutilon theophrasti* medik.), to survive the composting and mushroom growing process provides a useful worst-case example. Horowitz & Taylorson (1984) tested hard Velvetleaf seeds to various heating, time and moisture exposures to test seed viability and germination rates. They found that:

1. Velvetleaf seeds in the hard impermeable state will not germinate;
2. Velvetleaf seeds that had become permeable achieved near 100% germination over 48 hours at temperatures between 15 and 35°C;
3. 50% of hard seeds became permeable after 1 hour at 68°C under humid (composting) conditions;
4. Velvetleaf seed viability declined to 66% after 1 hour exposure to 70°C and 17% when exposed to 80°C;
5. Impermeable (hard) seeds are considerable more tolerant of heat than permeable (soft) Velvetleaf seeds.

From these results, and in consideration of the composting and mushroom growing process described in section 2, it should be expected that the majority of hard (impermeable) Velvetleaf seeds included as contaminants in the original compost ingredients would be made

either permeable or unviable by heat and moisture exposure during phases 1 and 2. The viable permeable seeds would then be expected to germinate during the production of phase 3 compost and be removed before packaging and shipping to New Zealand. Any seed that germinates during the incubation period (phase 3 compost production) could be removed by the production facility or likely be killed during export at the temperatures used for storage (- 2°C).

From the combined information above it can be surmised that under windrow composting systems, due to slow heat-up times and uneven heating, the time required to sterilise the phase 1 compost of weed seeds is likely to be over 10 days. However as the surviving seeds cannot "re-infect" the compost the phase 1 composting process should be expected to significantly reduce viable seed numbers.

Using composting systems where even heating occurs throughout the compost pile ensuring all of the compost is heated to the target temperatures allows for considerable less time to achieve adequate sterilisation of weed seeds. Temperatures as low as 60°C for 3 or more hours should be considered appropriate for most seed types under direct heating systems, especially when phase 1 and phase 2 composting periods are both undertaken. For the most temperature tolerant weed seed species, subsequent cold storage at temperatures below 0°C could be considered sufficient.

4.1.5 Risk management on arrival in New Zealand

Several options are available on arrival in New Zealand for the management of any potential unwanted commodity infestation. These options include:

- use of pest resistant strains of *Agaricus bisporus;*
- use of insecticide or disinfectant sprays or solutions on the mushroom beds;
- strict hygiene protocols including the mushroom growing rooms, worked access and clothing, and equipment sterilisation etc;
- pasteurisation (cookout) (at 65-70°C for more than 8 hours (Kilpatrick *et al*. 2015)) of the imported compost after use (e.g. spent compost).

The efficacy of these measures both individually or in combination will depend on the biology of the target organism, and will be discussed for each pest assessed in Chapter 5.

4.2 Assumptions and uncertainties

There is considerable uncertainty about the efficacy of risk management measures against the possible hosts of viruses, and against microorganisms of potential economic concern. The use of interception data once trade has commenced is one method of monitoring efficacy, as records of live and dead organisms indicate the success of a treatment and other risk management measures and the likelihood of surviving the import process. However, interception records can rarely be used quantitatively because of limitations in the identification and recording processes.

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5 Risk analysis of potential hazard organisms

A list of the potential pests associated with phase 3 mushroom compost is provided in the Appendix (***Table 1***) along with their hazard status.

Given the extent of the heating and processing undertaken during the production of phase III mushroom compost, much of which is designed to remove pest or disease organism contaminations, only two particularly significant organisms were selected for a full risk analysis:

- Mushroom Virus X or MVX complex (see section *5.1*)
- *Trichoderma aggressivum* f. *europaeum* Samuels & W. Gams (see section *5.2*)

All other organisms listed as being potential hazards associated with phase 3 mushroom compost (see the Appendix) are either expected to be managed by standard production practices (see Section 4) or are unlikely to cause substantive impacts in New Zealand (see the Appendix). Measures appropriate to the management of the biosecurity risks of the mushroom virus or *Trichoderma* species are also expected to manage the biosecurity risks presented by any of the other potential hazards. Details of these assumptions and an analysis of the expected management of pests other than the mushroom virus or *Trichoderma* species are provided in Section 4 of this assessment.

5.1 Mushroom Virus X

Scientific name: Mushroom Virus X or MVX (complex)

Other relevant scientific name[s]: Brown Cap Mushroom Virus or BCMV (part of complex)

5.1.1 Hazard identification

5.1.1.1 *Description*

MVX or Mushroom Virus X is a mycovirus (fungi-infecting virus), which as a group are widespread in fungi, including plant pathogenic fungi. In most cases, they are reported to be cryptic or show few symptoms, leading to latent infection in host (fungal) cells (Pearson *et al*. 2009). Mycoviruses are distinct from those viruses that use fungi as vectors because mycoviruses are able to replicate within the fungal host (Rochon *et al*. 2004).

5.1.1.2 *Taxonomy*

MVX or Mushroom Virus X (otherwise known as Brown Cap Mushroom Virus or BCMV) is a relatively new virus disease of mushrooms (mycovirus) that has affected the Irish mushroom industry since the late 1990's (Grogan 2011). Because of some similarity in symptoms, the disease was at first linked erroneously to *La France Isometric Virus* (LIV) (which is reported as being present in New Zealand (Sharma *et al*. 2007)).

A number of viruses are believed to make up the MVX complex (Burton *et al*. 2011). Brown mushroom symptoms and poor mushroom quality are believed to be caused by *Agaricus bisporus* Virus 16 (AbV16). AbV16 is usually found in association with other viruses, however it is not clear what effect (if any) other viruses in the MVX complex have on mushroom quality, or if these viruses interact with AbV16 (H Grogan, pers. comm.). However, Fleming-Archibald *et al*. (2016) note that two other viruses, *Agaricus bisporus* Virus 6 (AbV6) and *Mushroom bacilliform virus* (MBV), may also contribute to symptoms.

Farms in The Netherlands, South Africa, New Zealand, and Italy have reported symptoms characteristic of MVX and early molecular tests appeared to confirm the presence of MVX in samples from these locations (Kaur 2002, Pudełko 2010). But unlike the known mushroom virus (LIV) that normally carries a specific set of dsRNAs, in the case of MVX the number of dsRNAs, their range, size and distribution over the samples is different. The dsRNAs in their electrophoretic patterns did not resemble those previously described in *Agaricus bisporus* (white-buttoned mushroom) and were substantially different from those characteristic of LIV (Pudełko 2010).

5.1.1.3 *Exporting country[s] status*

MVX has been reported from compost-producing and mushroom growing facilities in The Netherlands and elsewhere in Europe.

5.1.1.4 *New Zealand status*

Because of some similarity in symptoms, the disease was at first linked erroneously to LIV (which is reported to be present in New Zealand (Sharma *et al*. 2007)). A report of MVX disease being present in New Zealand (Kaur 2002) stated that MVX symptoms had been seen in New Zealand mushrooms, and that testing of symptomatic samples detected virus sequences associated with the disease. However this unpublished report is not considered sufficient evidence to verify the presence of the disease in New Zealand, and there are no records of MVX being detected subsequently, or of symptoms of MVX being observed in New Zealand. As such, MVX is a regulated organism that is considered to be absent from New Zealand.

It is possible that as a virus complex, one or more (but not all) of the viruses involved in the complex are present in New Zealand but remain symptomless (and potentially undetected).

5.1.1.5 *General geographic distribution*

MVX has been reported from Belgium, Ireland, Italy, The Netherlands, Poland and South Africa (Burton *et al*. 2011, Eastwood 2015; Pudelko 2010) but viruses in the complex may be more widespread in Europe or elsewhere but as yet unreported.

5.1.1.6 *Commodity association*

Transmission of the MVX viruses is thought to be via infected spores and/or infected mycelium of *Agaricus bisporus* (Burton *et al*. 2011) and potentially other fungal species which may be present in phase III mushroom compost (e.g. *Trichoderma* species, although this cannot be confirmed until the taxonomic issues are resolved).

5.1.1.7 *Potential for establishment and impact*

The effects of MVX on mushroom yield and quality have resulted in economic difficulties and even farm closures (Burton *et al*. 2011). Hygiene measures have resulted in some limited success in controlling the disease (Burton *et al*. 2011). Viruses associated with mushroom spawn will be expected to establish in a new area if the mushroom spawn in used to produce mushrooms.

5.1.1.8 *Hazard identification conclusion*

Given that MVX:

- Is associated with commodity;
- Is present in the exporting country;

- Is not recorded from NZ;
- Can potentially establish in New Zealand;
- Can potentially cause unwanted impacts;

MVX is therefore considered a hazard on phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe.

5.1.2 Risk assessment

5.1.2.1 *Biology*

A disease of mushrooms first described in the 1990s, MVX continues to cause serious economic damage to the European mushroom industry. The disease is associated with the presence of double-stranded RNA (dsRNA) molecules, 26 dsRNAs have been size separated, and up to 16 have been found in a single sample (Eastwood *et al*. 2015). Recent work has considered *Agaricus bisporus* Virus 16 (AbV16) to be the causal agent. AbV16 is usually found in association with other viruses, however it is not clear what effect (if any) other viruses in the MVX complex have on mushroom quality, or if these viruses interact with AbV16 (H Grogan, pers. comm.)

MVX causes a diverse range of symptoms, including pinning disruption, crop delay, premature veil opening, various fruit-body abnormalities, and discoloured mushroom caps, ranging from off-white to brown (which for the sake of clarity will be referred to here as the brown symptom) (Burton *et al*. 2011). The various symptoms can occur either singularly or in combination but mostly are associated with loss of crop yield or product quality (Pudełko 2010). The main symptom is "brown" or "off coloured" mushrooms of reduced quality, which leads to the dumping of produce by growers or the rejection of produce by the retailers, thereby disrupting the supply chain and causing economic losses for the growers (Grogan 2011). In the first years of the virus emergence as a disease, the crops of 80% of commercial mushroom growers in Great Britain were affected; losses amounted to £50 million. Such losses resulted in mushroom farm closures and the loss of nearly 800 jobs (Pudełko 2010).

Brown mushroom symptom expression is sporadic, transient and unpredictable, suggesting a complex aetiology involving unknown factors (Grogan 2011). It is now clear that the collection of MVX ds-RNAs represents a complex of different viruses which may account for the diversity of symptoms (Burton *et al*. 2011).

Hygiene measures have resulted in some limited success in controlling the disease. However MVX still represents a largely uncharacterised disease with little known about the causative agents (Burton *et al.* 2011) although work on characterising the disease is progressing (Eastwood *et al*. 2015).

Aetiology of MVX

Mycoviruses have no known extracellular mode of transmission and under natural conditions are reliant on their fungal hosts for intracellular transmission. This can occur in two ways, horizontally via protoplasmic fusion and vertically by sporulation (Pearson *et al*. 2009). Therefore mycoviruses are transmitted within the mushroom tissue (mycelium) that grows through the mushroom compost as well as through the spores produced by the mushrooms (Grogan 2011). Symptom expression from mycelial infection appears to depend on the time and degree of infection as well as the type or strain of the infecting mycelium (Burton *et al.* 2011).

In experiments it was found that a low rate of infected material (0.01% or a few grams) incorporated into compost or casing at the end of the compost incubation period gave the most consistent symptoms compared to higher or lower rates (Grogan 2011; Fleming–Archibald *et al*. 2015). Therefore to avoid infection, mushroom compost and/or casing

should not come into contact with any infective material (from previously infected crops) at this time (Grogan 2011).

Following a point-infection of MVX into Phase 3 mushroom compost it was found to move at least 4 metres (the length of the compost studied) within a single cropping period (Grogan 2011).

5.1.2.2 *Entry assessment*

Fleming–Archibald *et al*. (2015) listed the following as routes of contamination of BCMV (associated with MVX) by infested compost or casing fragments (infested with infected mycelia):

- Infected compost debris can infiltrate Phase 3 tunnels at spawning or during spawn run;
- Infested Phase 3 compost can infest transport vehicles and filling equipment, especially conveyors and filling heads that are difficult to clean;
- Infested crops that are not steam sterilised will generate a high load of contaminated compost and casing fragments [*as well as infected mushroom spores* (Grogan 2011)]. These will be deposited throughout the farm and on filling and casing machinery, equipment and haulage trucks;
- Infested compost and casing fragments [*as well as infected mushroom spores* (Grogan 2011)] deposited around the farm or compost facility can be blown around on windy days to re-infest cleaned conveyors, machinery, equipment, and haulage trucks;
- Phase 3 mushroom compost could also become contaminated by infected spawn (Grogan 2011).

Fleming–Archibald *et al.* (2015) also note that only a tiny amount (a 'pinch') of infested material is required to spread the virus. They also noted that viruses can move rapidly in Phase 3 compost (e.g. through the depth of the compost in two days) presumably through the growth of infected mycelia.

While MVX can spread rapidly through Phase 3 compost with the growth of the host fungus, symptoms of infection will not become apparent until the mushroom caps form (or fail to form when expected to). As Phase 3 compost is exported in the pre-capping stage of mushroom development, there will be no apparent (visual) evidence of MVX infestation.

Given that:

- Infestation of Phase 3 compost by MVX is difficult to prevent in commercial composting facilities;
- Phase 3 compost infested with MVX will not be apparent on export;

The likelihood of entry is considered to be high from facilities that are contaminated with MVX.

5.1.2.3 *Exposure assessment*

As the Phase 3 compost will be directly used for producing a mushroom crop without further treatment, exposure of MVX to the New Zealand environment from infested compost is certain.

The likelihood of exposure is therefore considered to be high.

5.1.2.4 *Assessment of establishment and spread*

The likelihood of MVX establishing and spreading in New Zealand is characterised in the same manner as the likelihood of the Phase 3 compost becoming infested and entering New Zealand on imported material.

Fleming–Archibald *et al*. (2015) listed the following as routes of contamination of BCMV (associated with MVX) by infested compost or casing fragments (infested with infected mycelia):

- Infected compost debris can infiltrate Phase 3 tunnels at spawning or during spawn run;
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Fleming–Archibald *et al*. (2015) also note that only a tiny amount (a 'pinch') of infested material is required to spread the virus. They also noted that viruses can move rapidly in Phase 3 compost (e.g. through the depth of the compost in two days) presumably through the growth of infected mycelia.

The prevalence and impacts of MVX in Europe illustrate the difficulties the industry has experienced in controlling or limiting infestations in commercial facilities. New Zealand industry reports the same difficulties controlling *La France Isometric Virus* (LIV). It should therefore be expected that the use of infested Phase 3 compost will contaminate the facility in New Zealand.

Spread of MVX between facilities is reliant on the movement of contaminated machinery, equipment or personnel from an infested facility to one that is not infested and geographically distant. It also relies on the contaminated machinery, equipment or personnel coming into contact with the pre-production compost in the other facility. While measures such as cleaning can be implemented to reduce the likelihood of such spread, experience in northern Europe clearly illustrates the difficulties in preventing spread even when knowledge of the potential risks are widely known and understood by industry. How this would apply to the New Zealand context is unclear, however one possible inter-facility pathway could be the movement of mushroom packing trays.

Given that:

- Infested Phase 3 compost will contaminate a commercial mushroom facility;
- Commercial mushroom producers in Europe experience difficulties preventing the contamination of facilities and the spread of MVX between facilities even with high industry awareness and targeted preventative measures;

The likelihood of MVX establishing and spreading within New Zealand from infested Phase 3 mushroom compost is considered to be moderate to high.

5.1.2.5 *Consequence assessment*

Economic consequences

In the first years of the virus emergence as a disease, the crops of 80% of commercial mushroom growers in Great Britain were affected; losses amounted to £50 million. Such

losses resulted in mushroom farm closures and the loss of nearly 800 jobs (Pudełko 2010). Grogan (2007) noted that UK growers have now been able to significantly reduce or eliminate the effects of MVX, and that disease is decreasing in terms of its significance to the British mushroom industry. Similarly, Grogan (2011) noted that reviewing the hygiene procedures and weaknesses on sites where MVX is present has resulted in most affected farms in Britain becoming clear of the problem. It is likely that a similar impact would occur on the New Zealand mushroom industry, with significant losses occurring as industry is forced to upgrade facilities to adequately manage the disease.

The New Zealand industry is currently generating around $45 million in domestic and export sales (FreshFacts 2015) much of which would be impacted by the introduction of MVX both in terms of production losses and loss of production capability (closed facilities).

The potential economic consequences to the mushroom industry within New Zealand from MVX establishment and spread should be considered high.

Environmental consequences

No recorded environmental impacts could be found from MVX disease in those countries that have the disease in commercial facilities. Therefore there is unlikely to be any environmental impacts in New Zealand from MVX.

The potential environmental consequences within New Zealand are considered to be negligible.

Human health consequences

There are no recorded human health impacts from MVX.

The potential human health consequences within New Zealand are considered to be negligible.

Socio-cultural consequences

MVX would be expected to have some impacts on non-commercial (home grown) mushroom production which is common but not widespread in New Zealand.

The potential socio-cultural consequences within New Zealand are considered to be low.

5.1.2.6 *Risk estimation*

Given that:

- the likelihoods of entry and exposure of MVX from contaminated facilities are high; and
- the establishment and spread of MVX in New Zealand from infested Phase 3 mushroom compost is considered to be moderate to high; and
- the impacts of MVX on the mushroom industry in New Zealand are expected to be significant;

the risk estimation for MVX in phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe is moderate. Therefore MVX is considered to be a risk associated with phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe.

5.1.3 Risk management options

MVX can contaminate mushroom (*Agaricus bisporus*) spores and mycelium, mushroom compost and casings, and equipment used in mushroom production and storage (Grogen 2010; Fleming–Archibald *et al*. 2015). Effective risk management needs to consider all sources of contamination with MVX, for example:

- Ensuring imported mushroom inoculum used in Phase 3 mushroom compost production is free of MVX.
- Ensuring mushroom compost is treated during production and all treated product is protected from re-infestation.
- Ensuring all used containers and equipment associated with mushroom production is disinfected (if non-absorbent) or treated (if absorbent).

The following risk management options cover measures for inoculum, compost and associated equipment. In the case of compost and associated equipment, the focus is not on treating the virus itself, but on removing the host fungus. If the host fungus is removed or destroyed, the virus is effectively rendered non-infective.

5.1.3.1 *Testing Measures (ensuring inoculum is free from MVX)*

Inoculum can be tested directly or compost can be tested after inoculation.

A new diagnostic technique based on PCR, has been developed that can detect both forms of MVX (browning symptom and pinning disruption symptom) at low levels in spawn-run or Phase III compost. This test can be predicative to detect the presence of MVX in compost, providing advanced warning to growers (i.e. before cropping), it can be used to identify the sources of infection and it could be used to certify compost as MVX-free (Burton *et al*. 2011).

As only a tiny amount (a 'pinch') of material infested with MVX (Fleming–Archibald *et al.* 2015) or its host fungi (e.g. *Trichoderma* species (O'Brien *et al*. 2017)) is required to infest the compost, even the most dilute contamination levels will result in a contaminated facility.

Testing of the compost to verify freedom from MVX or the host fungi is unlikely to be a suitable option on its own, although could be used as part of a system of measures.

Testing and indexing of parental cultures (from which spores are collected) for MVX freedom is a more achievable and reliable method of ensuring compost does not become infested with MVX when mixing in mushroom spawn. Facilities that are purpose-built and operated to ensure spawn remain free of contaminants, including using well trialled and accurate testing methods, therefore can provide reliable confirmation of spawn freedom from MVX. It should be noted, however, that MVX is a virus complex of which not all members have necessarily been identified or fully characterised. Testing for a selected few of the members of the complex may not ensure other members do not enter on Phase 3 mushroom compost or on other forms of inoculum imported into New Zealand.

5.1.3.2 *Options for Treatment*

The only feasible option for treating compost for biological contaminants is heating, as this is already a part of the production process. Fleming-Archibald *et al.* (2015) state that to eliminate MVX from compost the entire shipment would need to be heated to a minimum of 65°C for at least 8 hours. No specific evidence was provided by the authors on the efficacy of this treatment, or whether shorter exposure periods or lower temperatures would also attain suitable levels of efficacy.

From the more general literature review covered in section *4.1.4.2* of this document, under composting systems where even heating occurs throughout the compost pile ensuring all of the compost is heated to the target temperatures, temperatures as low as 65°C for 4 or more hours should be considered appropriate for all but the most thermophilic fungi.

The question then remains as to the potential for thermophilic fungi to contaminate the compost and act as a host of MVX. While it is possible that one or more of the viruses within the MVX complex may infect fungi more widely than *Agaricus bisporus*, the likelihood that all of the viruses within the complex (and therefore the disease) would be carried by any particular thermophilic fungi should be considered very low (remote).

5.1.3.3 *Options for Disinfestation*

While disinfectants can be used to kill fungi and with it the infesting virus, tests confirm it is not possible to kill all mycelium in compost using disinfectants (O'Neil *et al*. 2015). Even high levels of biocides for prolonged periods of time cannot reduce fungal or bacterial populations to zero in compost (O'Neil *et al*. 2015). Therefore all compost, casing soil and any other organic matter must be removed before disinfecting a porous or non-porous surface.

With regard to the spread of MVX from a contaminated facility to other as-yet uncontaminated facility through the movement of machinery, equipment, or personnel, experience from northern Europe indicates that the following measures need to be applied to all facilities:

- De-contaminate 'pasteurise tunnels' between batches.
- High personnel and equipment hygiene standards during spawning.
- De-contaminate all compost handling facilities and equipment between batches.
- Frequently de-contaminate transport equipment that moves between facilities
- Ensure all used compost and waste mushroom material is disposed of appropriately (heating (at 65-70°C for more than 8 hours (Kilpatrick *et al*. 2015))/burial).
- Segregate all machinery and equipment used at different steps (phases) of the process.
- Minimise airborne source of contamination, such as spores or microscopic compost fragments, using high-grade air filtration.

Infection can occur at compost facilities, in growing facilities during transportation, or in filling/emptying operations. Only tiny amounts of infected material are required to spread infection, and MVX will spread throughout the crop within a few days. As symptom expression is sporadic, transient and unpredictable, facilities can become infested and act as a source of infection for other facilities before the presence of MVX is confirmed.

In short, experience from northern Europe has shown that without the implementation of extensive hygiene activities in infested and non-infested mushroom production facilities, it is unlikely that MXV will be restricted to a single facility within a region.

5.1.3.4 *Options for Production Freedom*

Further options for preventing the import of contaminated Phase 3 mushroom compost include restricting the source of imported material from production sites confirmed as being free of MVX. The difficulty with any type of production site freedom is that hygiene methods have a mixed level of success in preventing MVX contamination of compost material, and detection of any contamination either by testing or through symptom expression during mushroom production may not occur for some time after export. For these reasons it may be difficult to ensure production sites remain free of MVX without continuous and comprehensive testing regime.

5.1.3.5 *Concluding Comments on Measures Options for MVX*

Given that general or specifically designed hygiene methods have a mixed level of success in preventing MVX contamination of compost material, and detection of compost production site contamination may be delayed for some time after infestation, some form of compost treatment may be required to provide an appropriate level of confidence that any imported phase 3 mushroom compost is free of MVX.

The critical components of the mushroom compost production process for the management of MVX are as follows:

- Mushroom inoculum used in mushroom spawn production may be collected from fungi growing media that have been indexed (tested) and found free of MVX.

- All mushroom compost may be heated for a minimum of 65°C for 4 hours. After heating the compost should be handled in a manner that prevents re-infestation and, once the Phase 3 mushroom compost has been produced, packed in non-absorbent sterile packaging and stored in areas free of MVX or organic contaminants in general.
- All used containers and equipment associated with mushroom production that may accompany the Phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe may be cleaned or organic material and disinfected if non-absorbent or if absorbent heated for a minimum of 65°C for 8 hours (Kilpatrick *et al*. 2015).

Should MVX arrive in New Zealand in contaminated mushroom compost, the success of any measures on the domestic mushroom production facilities, to ensure any imported contaminated compost does not result in the establishment of MVX in New Zealand, are also limited by the limited efficacy of hygiene and detection methods.

If a heat treatment is undertaken to ensure any mushroom compost is free of MVX, the treatment may need to involve operational conditions that ensure all (100% to core) of the mushroom substrate is subject to the minimum temperature requirement (65°C for 4 hours) as verified by measuring the coldest spot (e.g. the surface or centre of a compost pile).

5.1.4 References

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5.2 Trichoderma aggressivum f. europaeum

Scientific name:	*Trichoderma aggressivum* f. *europaeum* Samuels & W. Gams
Other relevant scientific name[s]:	**(**synonym) *Trichoderma harzianum* Th2
	Green mould disease

5.2.1 Hazard identification

5.2.1.1 *Description*

Ascomycete fungi of the genus *Trichoderma* are ubiquitously distributed in nature and commonly account for the majority of fungi cultured from soil samples from a variety of habitats. Based on a genomic comparison, mycoparasitism was proposed as the ancestral life-style of all *Trichoderma*. Fungi from the genus *Trichoderma* are pleiomorphic, the asexual (anamorphic) and sexual (teleomorphic) life-cycle stages display distinct morphologies and ecologies. Not all Trichoderma have a teleomorph, some (like *Trichoderma aggressivum*) have only been described in the asexual state (O'Brien 2012).

5.2.1.2 *Taxonomy*

Most of the literature published regarding *Trichoderma* in mushroom production during the 1990s uses the biotype nomenclature, classifying the most relevant *Trichoderma* strains as *Trichoderma harzianum* biotypes Th1, Th2, Th3 and Th4. Since then Th2 and Th4 were reclassified as *Trichoderma aggressivum* f. *europaeum* and *Trichoderma aggressivum* f. *aggressivum*, respectively (Samuels *et al*. 2002, O'Brien 2012).

5.2.1.3 *Exporting country[s] status*

Trichoderma aggressivum f. *europaeum* was originally identified in Ireland during an outbreak of severe green mould disease in the late 1980s. Subsequent outbreaks of severe green mould disease were reported in Britain, Spain, France, and across Northern Europe (O'Brien 2012).

5.2.1.4 *New Zealand status*

No records could be found of *Trichoderma aggressivum* f. *europaeum* in New Zealand and therefore it is not known to be present in New Zealand.

5.2.1.5 *General geographic distribution*

Trichoderma aggressivum f. *europaeum* is considered widely distributed in Europe (UK, France, Hungary, Netherlands, Spain) (O'Brien 2012) and has been reported from Sir Lanka (Jayalal & Adikaram 2007). *Trichoderma aggressivum* f. *aggressivum* is considered widely distributed in North America (Canada, USA, Mexico) (O'Brien 2012), and has been reported

from Australia (Clift & Shamshad 2009). Further 'green mould' epidemics have been reported from Japan, India and South America (Jayalal & Adikaram 2007) that are likely to have been caused by *Trichoderma aggressivum* or an as-yet unidentified epidemically-significant *Trichoderma* species.

5.2.1.6 *Commodity association*

Trichoderma aggressivum can contaminate mushroom (*Agaricus bisporus*) spores, mushroom compost and casings, and equipment used in mushroom production and storage. *Trichoderma aggressivum* f. *europaeum* can therefore contaminate imported Phase 3 *Agaricus bisporus* mushroom compost and any associated packaging (Kilpatrick *et al*. 2015, O'Brien 2012).

5.2.1.7 *Potential for establishment and impact*

Yield losses have been recorded in the region of 5-100 % resulting in the economic impact of *T. aggressivum* f. *europaeum* on the mushroom industry (Grogan 2011, Kilpatrick *et al*. 2015). The New Zealand industry is currently generating around $45 million in domestic and export sales (FreshFacts 2015) much of which would be impacted by the introduction of *T. aggressivum* f. *europaeum* both in terms of production losses and loss of production capability (closed facilities).

5.2.1.8 *Hazard identification conclusion*

Given that *T. aggressivum* f. *europaeum*:

- Is associated with commodity;
- Is present in the exporting country;
- Is not recorded from NZ;
- Can potentially establish in New Zealand;
- Can potentially cause unwanted impacts;

T. aggressivum f. *europaeum* is therefore considered a hazard on Phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe.

5.2.2 Risk assessment

5.2.2.1 *Biology*

T. aggressivum (forma) has specific attributes which allow it to grow better in mushroom substrate than other *Trichoderma* species, resist inhibition by *A. bisporus* metabolites and ultimately cause more severe reductions in mushroom yield (O'Brien 2012).

T. aggressivum is fast growing; malt extract agar (MEA) cultures typically grow at 1mm/hr at 27°C and half that rate at 17°C. Optimum growth temperatures are in the 25-30°C range on potato-dextrose agar (PDA), with growth significantly reduced at 35°C. *T. aggressivum* grows in mushroom substrate below the casing layer, the same area occupied by the bulk of *Agaricus bisporus* mycelium and the primary source of nutrients for the formation of fruiting bodies. *T. aggressivum* can colonise a large areas of substrate which also contain *A. bisporus* mycelium before any apparent antagonism becomes evident (O'Brien 2012).

Grogan (2011) noted that reports have indicated *T. aggressivum* f. *europaeum* can be detected in chicken manure, on Phase 2 pre-filters and in spawning halls.

The presence of *T. aggressivum* in mushroom compost causes bare areas on the casing surface from which no mushrooms form. This results from the activities of *T. aggressivum* beneath

the surface which may then grow through the casing layer producing visible green sporulation. The point at which *Trichoderma* green mould infection is identified in a mushroom crop varies with the severity and stage of infection as well as the *Trichoderma* species responsible. *T. aggressivum* is the species most commonly found (detected) growing within the mushroom substrate and may become evident to visual inspection after Phase III of mushroom production. Depending on the severity of infection the onset of symptoms may be delayed (O'Brien 2012).

T. aggressivum infection is also often identified during the cropping cycle when green-sporulating patches of mycelium become visible on the casing surface. Growers may be aware of a problem before the first appearance of *T. aggressivum* spores due to a restricted pattern in pinning or colonisation of casing layer by *A. bisporus* mycelium. Growers may also be unable to control compost temperature during room venting as a result of increased biological activity in infected compost due to the presence of *T. aggressivum*. At this stage, damage is already done to the crop as *T. aggressivum* colonises the mushroom substrate below the casing layer first and becomes highly antagonistic towards *A. bisporus* upon sporulation (O'Brien 2012).

Colavolpe *et al*. (2014) noted that co-cultivation with mushrooms favoured growth of *Trichoderma* species, with *Trichoderma* sp. failing to grow on non-sterilized substrates or grow well on axenic substrates.

5.2.2.2 *Entry assessment*

Spawning (the mixing of mushroom inoculum into the substrate) has been described as a prime point for infection of substrate by *T. aggressivum* (Grogan 2011). The spawning process necessitates access to the substrate which may allow transmission of *T. aggressivum* from workers and equipment. The spawn itself may present a source of easily available carbohydrate to give *T. aggressivum* a foothold in the substrate. This enables colonisation of the spawn grains by *T. aggressivum* before the outgrowth of *Agaricus bisporus*, which is likely to have a severe impact on the crop. Bulk Phase III compost goes through several mixing stages so it is possible to envisage how a small localised patch of *Trichoderma*-infected compost in a Phase 3 tunnel could be diluted quite efficiently throughout a sizeable proportion of the compost from the tunnel (Grogan 2011).

Insect and arthropod pests (e.g. mites and flies) have also been linked to the spread of *T. aggressivum*, as well as containers and equipment associated with mushroom production (Kredics *et al*. 2010).

Even a small pocket of *T. aggressivum* infected compost in a Phase 3 tunnel has the potential to affect a much greater proportion of that compost as a result of various opportunities for mixing and diluting the infected compost into the un-infected compost. Under these circumstances the *T. aggressivum* infected compost is unlikely to be "visible" therefore no alert will be raised. Furthermore there is a distinct possibility that growers receiving compost from one area of the tunnel may crop very well while growers receiving compost from a more contaminated area of the tunnel may experience total yield loss leading to a false conclusion that the compost is not the source (Grogan 2011).

Given that:

- Infestation of Phase 3 compost by *T. aggressivum* f. *europaeum* is difficult to prevent in commercial composting facilities;
- Phase 3 compost infested with *T. aggressivum* f. *europaeum* will not be apparent on export;

The likelihood of entry from facilities that are contaminated with *T. aggressivum* f. *europaeum* is considered to be high.

5.2.2.3 *Exposure assessment*

As the Phase 3 compost will be directly used for producing a mushroom crop without further treatment, exposure of *T. aggressivum* f. *europaeum* to the New Zealand environment from infested compost is certain.

The likelihood of exposure is therefore considered to be high.

5.2.2.4 *Assessment of establishment and spread*

The likelihood of *T. aggressivum* f. *europaeum* establishing and spreading in New Zealand is characterised in the same manner as the likelihood of the Phase 3 compost becoming infested and entering New Zealand on imported material.

Even a small pocket of *T. aggressivum* infected compost in a Phase 3 tunnel has the potential to affect a much greater proportion of that compost as a result of various opportunities for mixing and diluting the infected compost into the un-infected compost. Under these circumstance the *T. aggressivum* infected compost is unlikely to be "visible" therefore no alert will be raised.

Insect and arthropod pests (e.g. mites and flies) have also been linked to the spread of *T. aggressivum*, as well as containers and equipment associated with mushroom production. While measures such as cleaning can be implemented to reduce the likelihood of such spread, experience in northern Europe clearly illustrates the difficulties in preventing spread even when knowledge of the potential risks are widely known and understood by industry.

Given that:

- Infested Phase 3 compost will contaminate a commercial mushroom facility;
- European commercial mushroom producers experience difficulties preventing contamination and spread of *T. aggressivum* f. *europaeum* even with high industry awareness;

The likelihood of *T. aggressivum* f. *europaeum* establishing and spreading within New Zealand from infested Phase 3 mushroom compost is considered to be moderate to high.

5.2.2.5 *Consequence assessment*

Economic consequences

Yield losses have been recorded in the region of 5-100 % resulting in the economic impact of *T. aggressivum* f. *europaeum* on the mushroom industry (Grogan 2011, Kilpatrick *et al*. 2015). The New Zealand industry is currently generating around $45 million in domestic and export sales (FreshFacts 2015) much of which would be impacted by the introduction of *T. aggressivum* f. *europaeum* both in terms of production losses and loss of production capability (closed facilities).

The potential economic consequences to the mushroom industry within New Zealand from *T. aggressivum* f. *europaeum* establishment and spread should be considered high.

Environmental consequences

No recorded environmental impacts could be found from *T. aggressivum* f. *europaeum* in those countries that have the disease in commercial facilities. Therefore there is unlikely to any environmental impacts in New Zealand from *T. aggressivum* f. *europaeum*.

The potential environmental consequences within New Zealand are considered to be negligible.

Human health consequences

There are no recorded human health impacts from *T. aggressivum* f. *europaeum*, although *Trichoderma* species have been recorded as causing allergic responses to exposed workers.

The potential human health consequences within New Zealand are considered to be negligible.

Socio-cultural consequences

T. aggressivum f. *europaeum* would be expected to have some impacts on non-commercial (home grown) mushroom production which is common but not widespread in New Zealand.

The potential socio-cultural consequences within New Zealand are considered to be low.

5.2.2.6 *Risk estimation*

Given that:

- the likelihoods of entry and exposure of *T. aggressivum* f. *europaeum* from contaminated facilities are high; and
- the establishment and spread of *T. aggressivum* f. *europaeum* in New Zealand from infested Phase 3 mushroom compost is considered to be moderate to high; and
- the impacts of *T. aggressivum* f. *europaeum* on the mushroom industry in New Zealand are expected to be significant;

the risk estimation for *T. aggressivum* f. *europaeum* in phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe is moderate. Therefore *T. aggressivum* f. *europaeum* is considered to be a risk associated with phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe.

5.2.3 Risk management options

T. aggressivum f. *europaeum* can contaminate mushroom (*Agaricus bisporus*) spawn, mushroom compost and casings, and equipment used in mushroom production and storage (Kilpatrick *et al*. 2015). Effective risk management needs to consider all sources of contamination with *T. aggressivum* f. *europaeum*, for example:

- Ensuring imported mushroom spawn used in mushroom production is free of *T. aggressivum* f. *europaeum*.
- Ensuring mushroom compost is treated during production and all treated product is protected from re-infestation.
- Ensuring all used containers and equipment associated with mushroom production are suitably cleaned of organic material and disinfected (if non-absorbent) or treated (if absorbent).

The following risk management options cover measures for inoculum, compost and associated equipment.

5.2.3.1 *Testing Measures*

Early detection of infection is crucial when *T. aggressivum* is involved. Culture based screening of compost and raw materials is a method for monitoring *Trichoderma* levels on a farm or composting facility, however species assignment in such cases is usually presumptive (O'Brien 2012). The taxonomy of the genus *Trichoderma* is complex and many *Trichoderma* species are difficult to identity to species level based on microscopic examination of morphological characteristics. Molecular PCR-based techniques have been used to differentiate between the ubiquitous *T. harzianum* (Th1) and *T. aggressivum* f. *europaeum*,

previously known as *T. harzianum* (Th2) and this method is useful for identifying pure cultures of *T. aggressivum* isolated from mushrooms or compost but it is not very successful for detecting *T. aggressivum* in compost samples (Grogan 2011). A direct PCR method can be used to detect *T. aggressivum* from mushroom substrate, which may be useful for monitoring purposes. This cannot be employed in all stages of the composting process as personnel are excluded (i.e. bunker (compost incubation) stages of Phases 2 and 3) (O'Brien 2012).

O'Brien *et al*. (2017) reported that *Trichoderma aggressivum* inoculum dilution level was shown to correlate well with mushroom yield with reductions of 2–6 % at the most dilute level and 60– 100 % at the most concentrated level, depending on the experiment. However they also noted that even when using the most sensitive testing methods, false negatives were reported on one occasion with the most dilute samples.

Baars *et al.* (2011) developed a method for detecting specific volatiles emitted by *T. aggressivum* growing in mushroom substrate in vitro using GC/MS. This is further developed in Baars *et al.* (2012) and presents an attractive potential method for the detection of *T. agressivum*. Sampling the head-space gases from sealed tunnels can identify *Trichoderma* infection on a species specific level while eliminating the requirement for access and has limited sampling problems associated with other methods.

Even a small pocket of *Trichoderma* infected compost in a Phase 3 tunnel has the potential to affect a much greater proportion of that compost as a result of various opportunities for mixing and diluting the infected compost into the un-infected compost. Under these circumstances the *Trichoderma* infected compost is unlikely to be "visible" therefore no alert will be raised. Furthermore there is a distinct possibility that growers receiving compost from one area of the tunnel may crop very well while growers receiving compost from a more contaminated batch of compost may experience total yield loss leading to a false conclusion that the compost is not the source (Grogan 2011).

5.2.3.2 *Options for Treatment*

Fungicides can be used to control the growth of *T. aggressivum*, however there have been reports of *T. aggressivum* strains resistant to fungicides (O'Brien 2012).

The only feasible option for treating compost for biological contaminants is heating, as this is already a part of the production process. The conditions needed during pasteurisation of Phase I compost to eradicate inoculum of *T. aggressivum* f. *europaeum* to below a detectable limit were determined to be 60°C for 12 hours (Grogan 2011). The results indicated that both *Trichoderma* spores and *Trichoderma*-infected compost were highly temperature tolerant and survived 57°C for 8 hours. They could also survive in moderately high ammonia concentrations of 300 ppm for several hours (Grogan 2011). The pasteurisation requirement was not increased for dry (69% moisture) Phase I compost compared with normal (74% moisture) compost (Grogan 2011). Three types of *Trichoderma* viability testing were used at casing. The detection limit using dilution plating was 10 cfu/g compost. This corresponded with visible *Trichoderma* growth from compost on semi-selective agar, and severe or even complete mushroom yield loss compared with a non-infected control compost (Grogan 2011). However even a small pocket of *Trichoderma* infected compost in a Phase 3 tunnel has the potential to affect a much greater proportion of that compost as a result of various opportunities for mixing and diluting (to less than 10 cfu/g compost) the infected compost into the un-infected compost (Grogan 2011).

In the event of a green mould outbreak, a pasteurisation temperature of 60°C should be maintained for 12 hours (Grogan 2011), although from the more general literature review covered in section *4.1.4.2* of this document, under direct heating systems temperatures of 65°C for 4 or more hours should be considered appropriate for all but the most thermophilic fungi.

5.2.3.3 *Options for Disinfestation*

While disinfectants can be used to kill fungi, tests confirm it is not possible to kill all mycelium in compost using disinfectants (O'Neil *et al*. 2015). Even high levels of biocides for prolonged periods of time cannot reduce fungal or bacterial populations to zero in compost (O'Neil *et al*. 2015). Therefore all compost, casing soil and any other organic matter must be removed before disinfecting a porous or non-porous surface.

With regard to the spread of *T. aggressivum* f. *europaeum* from a contaminated facility to other as-yet uncontaminated facility through the movement of machinery, equipment, or personnel; experience from northern Europe indicates that the following measures need to be applied to all facilities (not just those that are infested) to limit spread (Kilpatrick *et al*. 2015):

- De-contaminate 'pasteurisation tunnels' between batches.
- High personnel and equipment hygiene standards during spawning.
- De-contaminate all compost handling facilities and equipment between batches.
- Frequently de-contaminate transport equipment that moves between facilities.
- Ensure all used compost and waste mushroom material is disposed of appropriately (heating (at 65-70°C for more than 8 hours (Kilpatrick *et al*. 2015))/deep burial).
- Segregate all machinery and equipment used at different steps (phases) of the process.
- Minimise airborne source of contamination, such as spores or microscopic compost fragments, using high-grade air filtration.

Infection can occur at compost facilities, within growing facilities during across-site transportation, or in filling/emptying operations. Only tiny amounts of infected material are required to spread infection, and the fungus will spread throughout the crop within a few days depending on initial inoculum levels (Obrien *et al*. 2016). As symptom expression is sporadic, transient and unpredictable, facilities can become infested and act as a source of infection for other facilities before the presence of *T. aggressivum* f. *europaeum* is confirmed.

In short, experience from northern Europe has shown that without the implementation of extensive hygiene activities in infested and non-infested mushroom production facilities, it is unlikely that *T. aggressivum* f. *europaeum* will be restricted to a single facility within a region.

5.2.3.4 *Options for Production Freedom*

Further options for preventing the import of contaminated Phase 3 mushroom compost include restricting the source of imported material from production sites confirmed as being free of *T. aggressivum* f. *europaeum*. The difficulty with any type of production site freedom is that hygiene methods have a mixed level of success in preventing *T. aggressivum* f. *europaeum* contamination of compost material, and detection of any contamination either by testing or through symptom expression during mushroom production may not occur for some time after export. For these reasons it may be difficult to ensure production sites remain free of *T. aggressivum* f. *europaeum* without a continuous and comprehensive testing regime.

5.2.3.5 *Concluding Comments on Measures Options for T. aggressivum f. europaeum*

Currently, rigorous hygiene is considered the best method for prevention of *T. aggressivum* f. *europaeum* infection. Steam cook-out after every crop, and use of disinfectant on surfaces and equipment, are now standard practice for reducing spread of all mushroom diseases in commercial production facilities. Given that general or specifically designed hygiene methods have a mixed level of success in preventing *T. aggressivum* f. *europaeum* contamination of compost material, and detection of compost production site contamination may be delayed for some time after infestation, some form of compost treatment may be

required to provide an appropriate level of confidence that any imported phase 3 mushroom compost is free of *T. aggressivum* f. *europaeum.*

The critical components of the mushroom compost production process for the management of *T. aggressivum* f. *europaeum* are as follows:

- Mushroom inoculum used in mushroom spawn production may be collected from fungi growing media that have been indexed (tested) and found free of *T. aggressivum* f. *europaeum*;
- All mushroom compost may be heated for a minimum of 60°C for 12 hours or 65°C for 4 hours. After heating the compost should be handled in a manner that prevents re-infestation and, once the Phase 3 mushroom compost has been produced, packed in non-absorbent sterile packaging and stored in areas free of *T. aggressivum* f. *europaeum* or organic contaminants in general;
- All used containers and equipment associated with mushroom production that may accompany the Phase 3 *Agaricus bisporus* mushroom compost imported from northern Europe may be cleaned or organic material and disinfected if non-absorbent or if absorbent heated for a minimum of 65°C for 8 hours (O'Brien 2012).

Should *T. aggressivum* f. *europaeum* arrive in New Zealand, the success of any measures on the domestic mushroom production facilities, to ensure any imported contaminated compost does not result in the establishment of *T. aggressivum* f. *europaeum* in New Zealand, are also limited by the limited efficacy of hygiene and detection methods.

If a heat treatment is undertaken to ensure mushroom compost is free of *T. aggressivum* f. *europaeum*, the treatment may need to involve operational conditions that ensure all (100% to core) of the mushroom substrate is subject to the minimum temperature requirement (60°C for 12 hours or 65°C for 4 hours) as verified by measuring the coldest spot (e.g. the surface or centre of a compost pile).

5.2.4 References

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Appendix: Potential Hazard List for Phase 3 Mushroom Compost

Like diseases of plants, diseases of mushrooms can be caused by fungi, bacteria or viruses. A variety of insect, mite and nematode pests can also affect production, directly by consuming tissue of *A. bisporus* (mycophagous pests) or indirectly by damaging the substrate. The presence of these organisms can cause allergies and they can be a nuisance to mushroom farm workers. Weed moulds; fungi that are capable of colonising the mushroom compost and out competing *A. bisporus* for available nutrients, can also cause economic loss (Woodhall *et al*. 2009). Table 1 provides a list of the organisms recorded as being directly associated with *Agaricus bisporus* mushroom production and for each a short description of factors that indicate their potential hazard to New Zealand. The hazard status is considered based on listings in the New Zealand Organisms Register (NZOR[9]), the Unwanted Organisms Register (UOR[10]) and the Biosecurity Organisms Register for Imported Commodities (BORIC[11]). Information from all of these databases is subject to verification before being considered valid, and as such are only provided as guidance.

Table 1: List of phytosanitary organisms potentially associated with phase 3 mushroom compost for *Agaricus bisporus* production, and their hazard status

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Bacterial pit, agent not known	Bacterial Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan, and common on mushrooms. **Introduction?** Associated with mushrooms **Impacts?** Causes Small dark slimy pits on caps.	Potential Hazard	Woodhall *et al*. (2009)
Burkholderia gladioli pv. *agaricicola* (Lincoln *et al.* 1991) Young *et al*. 1996 (soft rot)	Bacterial Pathogen of Mushrooms	**In NZ?** Absent (NZOR), Not listed (UOR) **On pathway?** In Europe **Introduction?** Associated with mushrooms **Impacts?** Common, with sporadic outbreaks occurring in mushrooms crops causing soft rot, mild lesions to deep pitting on caps.	Potential Hazard (Regulated Pest in BORIC)	Largeteau *et al*. (2010) Woodhall *et al*. (2009)
Ewingella americana Grimont *et al*. 1984	Bacterial Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** In UK but not common. **Introduction?** Associated with mushrooms **Impacts?** Browning in the centre of the stipes and may be accompanied by the collapse of internal tissues.	Potential Hazard (probably not a hazard)	Largeteau *et al*. (2010) Woodhall *et al*. (2009)

[9] http://www.nzor.org.nz/
[10] https://www1.maf.govt.nz/uor/searchframe.htm
[11] http://www.mpi.govt.nz/news-and-resources/resources/registers-and-lists/biosecurity-organisms-register-for-imported-commodities/

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Janthinobacterium agaricidamnosum sp. nov. Lincoln et al. 1999 (soft rot)	Bacterial Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Reported originally in the UK and France, now considered present wherever mushrooms are grown **Introduction?** Associated with mushrooms **Impacts?** Outbreaks in mushroom crops are rare.	Potential Hazard (probably not a hazard)	Largeteau *et al.* (2010) Woodhall *et al.* (2009)
Pseudomonas 'rectans' (Brown blotch disease)	Bacterial Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Originally reported in USA **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Mild infection and superficial light brown discoloration.	Potential Hazard	Woodhall *et al.* (2009)
Pseudomonas aeruginosa (Schroeter, 1872) Migula 1900 (Mummy disease)	Bacterial Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Mummy disease has been observed in the UK **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Outbreaks are rare, mushroom dries out and discolours; basal swelling of stipes.	Non-Regulated (BORIC)	Largeteau *et al.* (2010) Woodhall *et al.* (2009)
Pseudomonas agarici Young 1970 (Drippy gills)	Bacterial Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Considered present wherever mushrooms are grown **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Rare, but when found in mushrooms most severe in autumn and winter.	Non-Regulated (BORIC)	Largeteau *et al.* (2010) Woodhall *et al.* (2009)
Pseudomonas costantinii Munsch *et al.* 2002 (Brown blotch disease)	Bacterial Pathogen of Mushrooms	**In NZ?** Absent (NZOR), Not listed (BORIC/UOR) **On pathway?** Originally found in Finland **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Brown blotches on cap.	Potential Hazard	Largeteau *et al.* (2010) Woodhall *et al.* (2009)
Pseudomonas fluorescens Migula 1895 (Mummy disease)	Bacterial Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Present in the UK (strains) **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Possibly associated with mummy disease.	Non-Regulated (BORIC)	Largeteau *et al.* (2010) Woodhall *et al.* (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Pseudomonas gingeri (Ginger blotch)	Bacterial Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Occurs wherever mushrooms are grown **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Ginger blotches on cap.	Potential Hazard (Regulated Pest in BORIC)	Largeteau *et al*. (2010) Sanchez (2010) Woodhall *et al*. (2009)
Pseudomonas syringae van Hall 1902 (Brown blotch disease)	Bacterial Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Occurs wherever mushrooms are grown **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Brown blotches on cap.	Non-Regulated (BORIC)	Largeteau *et al*. (2010)
Pseudomonas tolaasii Paine 1919 (Brown blotch disease)	Bacterial Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Wherever mushrooms are grown **Introduction?** Direct contact, contaminated compost or introduced to the growing environment via air currents. **Impacts?** Brown blotches on cap; distortion and splitting.	Non-Regulated (BORIC)	Largeteau *et al*. (2010) Sanchez (2010) Woodhall *et al*. (2009)
Ascobolus leveillei	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Present in a range of habitats and rarely on mushroom compost probably due to better hygiene	Potential Hazard	Woodhall *et al*. (2009)
Aspergillus spp.	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (Regulated Pest in BORIC)	Woodhall *et al*. (2009)
Botryotrichum piluliferum Sacc. & Marchal	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient. Cause of plaster mould in the USA	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Botrytis cinerea Pers. (syn. *Botryotinia fuckeliana*)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Cephalotrichum purpureofuscum (Schwein.) S. Hughes (Whisker mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Likely to occur as part of the species in the whisker mould complex	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Cephalotrichum stemonitis (Pers.) Link (Whisker mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Likely to occur as part of the species in the whisker mould complex	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Chaetomium globosum (syn. *Chaetomium olivaceum*) (Olive-green mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Non-Regulated (BORIC)	Largeteau *et al*. (2010) Sanchez (2010)
Chromelosporium fulvum (Cinnamon brown mould)	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Chrysosporium merdarium (Yellow mould)	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Clitocybe rivulosa (Pers.) Fr. (syn. *Clitocybe dealbata*)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** North temperate distribution, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Clitopilus cretatus	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Coprinopsis atramentaria (Bull.) Redhead, Vilgalys & Moncalvo (*Coprinopsis* or ink cap fungi)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Coprinopsis cinerea (Schaeff.) Redhead, Vilgalys & Moncalvo (*Coprinopsis* or ink cap fungi)	Fungal Competitor on Compost	**In NZ?** Absent (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Coprinopsis radiata (Bolton) Redhead, Vilgalys & Moncalvo (*Coprinopsis* or ink cap fungi)	Fungal Competitor on Compost	**In NZ?** Absent (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Coprinus comatus (O.F. Müll.) Pers. (*Coprinopsis* or ink cap fungi)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Corticium sp. (identity not known)	Fungal Competitor on Compost	**In NZ?** Some species present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Corynascus thermophilus (Flour mould)	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** North America and Europe, recorded on straw and in mushroom compost. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Diehliomyces microspores (Diehl & E.B. Lamb.) Gilkey (False truffle)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on mushroom compost. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Heleococcum aurantiacum	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** In UK, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Humicola insolens	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Hydropisphaera peziza (Tode) Dumort.(syn. *Nectria peziza*)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Non-Regulated (BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Hypomyces chrysospermus (syn. *Sepedonium chrysospermum*) (Sepedonium yellow mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts and habitats. **Introduction?** A **Impacts?** Can cause necrosis on mushroom tissue but it is more common as a weed mould competitor	Potential Hazard (probably not a hazard)	Largeteau *et al*. (2010)
Hypomyces chrysospermus Tul. & C. Tul. (yellow mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts and can infect mushrooms	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Mortierella reticulata	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** May be cosmopolitan, recorded on compost. **Introduction?** In compost **Impacts?** Occurs on mushroom composts but is rare.	Potential Hazard	Woodhall *et al*. (2009)
Mucor mucedo Fresen.	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost and mushroom spawn **Impacts?** Occurs on mushroom composts but rare	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Myceliophthora lutea Costantin (mat and confetti)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts but rare	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Neurospora sitophila Shear & B.O. Dodge	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (Regulated Pest in UOR)	Woodhall *et al*. (2009)
Oedocephalum fimetarium (Riess) Sacc. (Brown mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** North America and NZ, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Oedocephalum glomerulosum (Bull.) Sacc. (Brown mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Panaeolus cinctulus (Bolton) Britzelm. (syn. *Panaeolus subbalteatus*) (weed panaeolus)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Papulaspora byssina (Plaster mould)	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient or cultivation systems inappropriate (e.g. wet and tight compost)	Potential Hazard	Largeteau *et al*. (2010) Woodhall *et al*. (2009)
Penicillium brevicompactum Dierckx	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan and occurs on a wide range of hosts/habitats **Introduction?** Airborne spores and in compost **Impacts?** Isolated from a decaying mushroom, probably also a cause of weed mould	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Penicillium chermesinium	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan and occurs on a wide range of hosts/habitats **Introduction?** Airborne spores and in compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Penicillium spp. (Smoky mould)	Fungal Competitor on Compost	**In NZ?** Some species present (NZOR), Not listed (UOR) **On pathway?** Cosmopolitan and occurs on a wide range of hosts/habitats **Introduction?** Airborne spores and in compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (Regulated Pest in BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Peziza vesiculosa Bull.	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** In North America and Europe and occurs on a wide range of hosts/habitats **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Podosordaria pedunculata	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** In Europe and occurs on a wide range of hosts/habitats **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Pythium hydnosporum	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR) **On pathway?** In North America and Europe, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (Regulated Pest in BORIC/UOR)	Woodhall *et al*. (2009)
Pythium oligandrum Drechsler	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Roumegueriella rufula (Berk. & Broome) Malloch & Cain	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Scopulariopsis coprophila (syn. *Scopulariopsis fimicola*) (Plaster mould)	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard (Regulated Pest in BORIC/UOR)	Largeteau *et al*. (2010) Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Sporendonema purpurescens (Lipstick mould)	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Largeteau *et al*. (2010) Woodhall *et al*. (2009)
Talaromyces emersonii Stolk (syn. *Geosmithia emersonii*)	Fungal Competitor on Compost	**In NZ?** Absent (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Trichoderma asperellum Samuels, Lieckf. & Nirenberg.	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Recorded in mushroom compost in Hungary. Appears to have a wide global distribution. **Introduction?** Easily contaminates facilities and equipment. Spores spread by pepper mites (*Pygmephorus* spp.*)*. Some *Trichoderma* species can contaminate spawn. **Impacts?** Used as a biocontrol agent.	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Trichoderma ghanense Yoshim. Doi, Y. Abe & Sugiy. (syn. *Trichoderma atroviride*)	Fungal Competitor on Compost	**In NZ?** Absent (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Occurs on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Trichoderma harzianum Rifai	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Some strains of *T. harzinum* are known to not cause problems in mushroom production.	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Trichoderma koningii Oudem.	Fungal Competitor on Compost	**In NZ?** Unknown (NZOR), Not listed (UOR) **On pathway?** North temperate on a range of hosts and habitats. **Introduction?** In compost **Impacts?** In the last decade this species is only considered to have caused very minor problems in the UK.	Non-Regulated (BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Trichoderma longibrachiatum Rifai	Fungal Competitor on Compost	**In NZ?** Absent (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** May occur on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Trichoderma pleuroticola S.H. Yu & M.S. Park (Green mould disease)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** May occur on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Largeteau *et al*. (2010) Sanchez (2010)
Trichoderma pleurotum (Green mould disease)	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** May occur on mushroom composts if hygiene measures are insufficient	Potential Hazard	Largeteau *et al*. (2010) Sanchez (2010)
Trichoderma pseudokoningii Rifai	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** May occur on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Trichoderma virens (J.H. Mill., Giddens & A.A. Foster) Arx	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Reported to be a weed mould in edible mushroom production in India. Recently recorded as a weed mould in UK causing economic loss.	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Trichoderma viride Pers. (green mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Presence indicates poor composting. In the last decade this species is considered to only have caused very minor problems.	Non-Regulated (BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Trichophaea abundans	Fungal Competitor on Compost	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** Reported to occur in mushrooms in South Africa.	Potential Hazard	Woodhall *et al*. (2009)
Trichothecium roseum (Pers.) Link (Plaster or Flour moulds)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** May occur on mushroom composts if hygiene measures are insufficient	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Trichurus spiralis Hasselbr. (Whisker mould)	Fungal Competitor on Compost	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Likely cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost **Impacts?** May occur on mushroom composts if hygiene measures are insufficient	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Volvariellal (syn. *Volvaria*) sp. (Fr.) P. Kumm.	Fungal Competitor on Compost	**In NZ?** Some species present (NZOR), Not listed (BORIC/UOR). Some are even cultivated for edible mushrooms. **On pathway?** Numerous species of this genus distributed worldwide. **Introduction?** In compost **Impacts?** May occur on mushroom composts if hygiene measures are insufficient	Potential Hazard	Woodhall *et al*. (2009)
Acremonium (syn. *Cephalosporium*) spp.	Fungal Pathogen of Mushrooms	**In NZ?** Some species present (NZOR), Not listed (BORIC/UOR). **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** White mycelium on fruiting body gills	Potential Hazard	Woodhall *et al*. (2009)
Aphanocladium album (Preuss) W. Gams	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Present on a wide range of hosts and habitats worldwide **Introduction?** In compost or as contaminant of spawn **Impacts?** Occasionally causes serious outbreaks in mushrooms	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Fusarium oxysporum Schltdl.	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Many forms listed as regulated and non-regulated (BORIC/UOR) **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** Damping off	Potential Hazard	Woodhall *et al*. (2009)
Fusarium solani (Mart.) Sacc.	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Many forms listed as regulated and non-regulated (BORIC/UOR) **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** Damping off	Potential Hazard	Woodhall *et al*. (2009)
Hormiactis alba	Fungal Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** Irregular brown spots. Not a serious disease in the UK.	Potential Hazard	Woodhall *et al*. (2009)
Hypomyces rosellus (Alb. & Schwein.) Tul. & C. Tul. (syn. *Cladobotryum dendroides*) (Cobweb disease)	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** Rapid mycelial growth over casing and mushrooms; cap spotting.	Potential Hazard (probably not a hazard)	Largeteau *et al*. (2010) Sanchez (2010) Woodhall *et al*. (2009)
Lecanicillium fungicola (Preuss) Zare & W. Gams (syn. *Verticillium fungicola*) (Dry bubble disease)	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** In compost or as contaminant of spawn **Introduction?** In compost or as contaminant of spawn **Impacts?** Lesions on mushroom cap.	Potential Hazard (probably not a hazard)	Largeteau *et al*. (2010) Sanchez (2010)
Lecanicillium psalliotae (Treschew) Zare & W. Gams	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost or as contaminant of spawn **Impacts?** Lesions on mushroom cap.	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Melanospora damnosa	Fungal Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts. **Introduction?** In compost or as contaminant of spawn **Impacts?** No recorded impacts.	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Mortierella bainieri (Shaggy stipe)	Fungal Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** Peeling stipe, dark brown discolouration, and coarse grey-white mycelium over casing.	Potential Hazard	Woodhall *et al*. (2009)
Mycogone perniciosa (Magnus) Delacr. (Syn. *Hypomyces perniciosus*) (Wet bubble disease)	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** Massively distorted caps (cauliflower-like) with drops of amber liquid, also small 'bubbles'.	Potential Hazard (probably not a hazard)	Largeteau *et al*. (2010) Sanchez (2010) Woodhall *et al*. (2009
Mycogone rosea Link	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan **Introduction?** In compost or as contaminant of spawn **Impacts?** White mould of mushroom.	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Paecilomyces penicillatus (Höhn.) Samson	Fungal Pathogen of Mushrooms	**In NZ?** Absent (NZOR), Not listed (BORIC/UOR) **On pathway?** Only one record of isolation from a decaying mushroom in Belgium. Has also been found on decaying plants and wood. **Introduction?** Airborne spores or in compost or as contaminant of spawn **Impacts?** Isolated from a decaying mushroom	Potential Hazard	Woodhall *et al*. (2009)
Sarocladium strictum (W. Gams) Summerb.(syn. *Acremonium strictum* W. Gams)	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Present on a wide range of hosts and habitats worldwide **Introduction?** In compost or as contaminant of spawn **Impacts?** Potentially causes chocolate brown patches on mushroom	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Simplicillium lamellicola (F.E.V. Sm.) Zare & W. Gams (Gill Mildew)	Fungal Pathogen of Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Cosmopolitan, recorded on a wide range of hosts and habitats. **Introduction?** In compost or as contaminant of spawn **Impacts?** Mildew apparently does little harm	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Trichoderma aggressivum f. *aggressivum* Samuels & W. Gams (Green mould disease) (syn. *T. harzianum* Th4)	Fungal Pathogen of Mushrooms	**In NZ?** Absent (NZOR), Not listed (UOR) **On pathway?** Contaminates Phase 3 compost, Present in North America **Introduction?** Easily contaminates facilities and equipment. Spores spread by pepper mites (*Pygmephorus* spp.). Some *Trichoderma* species can contaminate spawn. **Impacts?** Causes significant mushroom production losses	Potential Hazard (Regulated Pest in BORIC)	Largeteau *et al*. (2010) Sanchez (2010) Woodhall *et al*. (2009)
Trichoderma aggressivum f. *europaeum* Samuels & W. Gams (Green mould disease) (syn. *T. harzianum* Th2)	Fungal Pathogen of Mushrooms	**In NZ?** Absent (NZOR), Not listed (UOR) **On pathway?** Contaminates Phase 3 compost, Present in Europe **Introduction?** Easily contaminates facilities and equipment. Spores spread by pepper mites (*Pygmephorus* spp.). Some *Trichoderma* species can contaminate spawn. **Impacts?** Causes significant mushroom production losses	Potential Hazard (Regulated Pest in BORIC)	Largeteau *et al*. (2010) Sanchez (2010) Woodhall *et al*. (2009)
Verticillium fungicola var. *aleophilum*	Fungal Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** North America **Introduction?** In compost or as contaminant of spawn **Impacts?** Predominant cause of dry bubble (cap lesions, distortion and discolouration) in North America	Potential Hazard	Woodhall *et al*. (2009)
Verticillium fungicola var. *fungicola*	Fungal Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Thought to have recently spread to North America from Europe through the import of material or machines used for mushroom cultivation. **Introduction?** In compost, on machinery/equipment, or as contaminant of spawn **Impacts?** Predominant cause of dry bubble (cap lesions, distortion and discolouration) in Europe	Potential Hazard	Woodhall *et al*. (2009)
Henria psalliotae (Cecid)	Insect (Cecid)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Mycelium, stipe, cap.	Potential Hazard	Woodhall *et al*. (2009)
Heteropeza pygmaea (Cecid)	Insect (Cecid)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Mycelium, stipe, cap.	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Lestremia cinerea (Cecid)	Insect (Cecid)	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Mycelium, stipe, cap.	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Lestremia eucophaea (Cecid)	Insect (Cecid)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Mycelium, stipe, cap.	Potential Hazard	Woodhall *et al*. (2009)
Mycophila speyeri, Mycophila barnesi (Cecid)	Insect (Cecid)	**In NZ?** Not listed (NZOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Mycelium, stipe, cap.	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Achorutes armatus (Collembola)	Insect (Collembola)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Occasional pest of mycelium, stipe, cap, wet compost.	Potential Hazard	Woodhall *et al*. (2009)
Drosophila funebris (Fabricius, 1787) (Fruit fly)	Insect (*Drosophila*)	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Occasional pest of compost, cap.	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Diplopoda spp. (Millipede)	Insect (Millipede)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Rare pest of Stipe, compost.	Potential Hazard	Woodhall *et al*. (2009)
Colboldia fuscipes (Scatopsid)	Insect (Scatopsid)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Occasional pest of compost.	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Bradysia sp., *B. matogrossensis*	Insect (Sciarid)	**In NZ?** Some species present (NZOR), Not listed (BORIC/UOR). **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Many *Bradysia* species are already present in the UK but they are rarely recorded as pests on mushroom crops.	Potential Hazard	Woodhall *et al*. (2009)
Lycoriella sp., L. ingenua (Dufour, 1839) (Sciarid flies)	Insect (Sciarid)	**In NZ?** Some species present (NZOR), Not listed (BORIC/UOR). **On pathway?** Worldwide **Introduction?** In compost **Impacts?** Compost, stipe	Potential Hazard	Sanchez (2010) Woodhall *et al*. (2009)
Megasellia sp., *M. halterata* (Phorid flies)	Insect (Sciarid)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost **Impacts?** Mycelium, stipe, cap	Potential Hazard	Sanchez (2010) Woodhall *et al*. (2009)
Pullimosina heteroneura (Haliday, 1836) (Sphaerocerid)	Insect (Sphaerocerid)	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Worldwide **Introduction?** Compost and airborne **Impacts?** Occasional pest of compost.	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Arctoseius cetratus Sellnick	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide. **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Predatory mite	Potential Hazard	Woodhall *et al*. (2009)
Brennandania lambi Krczal. (Australian mushroom pygmy mite)	Mite (Acarina)	**In NZ?** Not listed (NZOR) **On pathway?** Australia **Introduction?** Primarily through infested spawn **Impacts?** Directly affect mushroom mycelia	Potential Hazard (Regulated Pest in BORIC/UOR)	Woodhall *et al*. (2009)
Caloglyphus mycophagus Megnin	Mite (Acarina)	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Worldwide. **Introduction?** Associated with mushrooms **Impacts?** Common mycophagous	Non-Regulated (BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Dendrolaelaps spp.	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide (not UK) **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Predatory mite	Potential Hazard	Woodhall *et al*. (2009)
Digamasellus fallax Leitner	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide (not UK) **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Predatory mite	Potential Hazard	Woodhall *et al*. (2009)
Dolichocybe keiferi Krantz	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** USA **Introduction?** Not known **Impacts?** Directly affect mushroom mycelia	Potential Hazard	Woodhall *et al*. (2009)
Linopodes antennaepes Banks	Mite (Acarina)	**In NZ?** Not listed (NZOR) **On pathway?** Europe **Introduction?** Compost **Impacts?** Common mycophagous	Potential Hazard (Regulated Pest in BORIC/UOR)	Woodhall *et al*. (2009)
Macrocheles spp.	Mite (Acarina)	**In NZ?** Indigenous species (NZOR), Not listed (BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Predatory mite	Potential Hazard	Woodhall *et al*. (2009)
Pediculaster fletchmanni Wicht	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Brazil **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Can be a cause for crop rejection due to their bright colour. Can be a nuisance to pickers and is known to cause allergies in humans but is otherwise harmless to mushrooms.	Potential Hazard	Woodhall *et al*. (2009)
Phorytocarpais fimetorum (syn. *Parasitus fimetorum*) Berlese	Mite (Acarina)	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Predatory mite	Non-Regulated (BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Pygmephorus athiasae Wicht (Red pepper mite)	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** France **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Feed on weed moulds, and are indicators of *Trichoderma*. Can cause crop rejection Due to contamination with their bright red bodies and be can a nuisance to pickers. *Pygmephorus sellnicki* is reported to cause allergies in humans but is otherwise harmless to mushrooms.	Potential Hazard	Woodhall *et al*. (2009)
Pygmephorus kneeboni Wicht (Red pepper mite)	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** USA **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Feed on weed moulds, and are indicators of *Trichoderma*. Can cause crop rejection Due to contamination with their bright red bodies and be can a nuisance to pickers. *Pygmephorus sellnicki* is reported to cause allergies in humans but is otherwise harmless to mushrooms.	Potential Hazard	Woodhall *et al*. (2009)
Pygmephorus murphyi Smiley (Red pepper mite)	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** USA **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Feed on weed moulds, and are indicators of *Trichoderma*. Can cause crop rejection Due to contamination with their bright red bodies and be can a nuisance to pickers. *Pygmephorus sellnicki* is reported to cause allergies in humans but is otherwise harmless to mushrooms.	Potential Hazard	Woodhall *et al*. (2009)
Pygmephorus spp. (Red pepper mites)	Mite (Acarina)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Feed on weed moulds, and are indicators of *Trichoderma*. Can cause crop rejection Due to contamination with their bright red bodies and be can a nuisance to pickers. *Pygmephorus sellnicki* is reported to cause allergies in humans but is otherwise harmless to mushrooms.	Potential Hazard	Woodhall *et al*. (2009)
Tarsonemus myceliophagus Hussey	Mite (Acarina)	**In NZ?** Not listed (NZOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Feed on the mycelial threads at the base of the stem causing stems damage and discolouration. Virus vectors.	Potential Hazard (Regulated Pest in BORIC/UOR)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Tarsonemus spp. *T. floricolus* (Canestrini & Fanzago)	Mite (Acarina)	**In NZ?** Indigenous species (NZOR), Not listed (BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Feed on the mycelial threads at the base of the stem causing stems damage and discolouration. Virus vectors.	Potential Hazard	Woodhall *et al*. (2009)
Tyrophagus putrescentiae (Schrank, 1781) (syn. *Tyrophagus lintneri*)	Mite (Acarina)	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycophagous and feeds on mushroom mycelium and tissue as well as moulds and a variety of organic material. If present in large numbers, can results in both large and small pits on the mushrooms caps.	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)
Aphelenchoides agarica	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** India **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** A*phelenchoides composticola* and *Ditylenchus myceliophagus* are the most important species of each genus with regards to mushroom production. These are both present in the UK but are relatively rare in UK mushroom crops. It is unlikely that other members of each species would pose more of a risk to UK mushroom crops, since UK mushroom farmers already manage the most aggressive species of each genus.	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides asterocaudatus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** India **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Aphelenchoides bicaudatus (Imamura, 1931)	Nematode (Mycophagous)	**In NZ?** Present (NZOR) **On pathway?** Australia, Europe **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides coffeae	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Australia **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Aphelenchoides composticola Franklin, 1957 (Eelworms, Cephalothecium disease)	Nematode (Mycophagous)	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Worldwide. **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium, potentially very damaging.	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Aphelenchoides cyrtus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Germany **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides dactylocercus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Europe, India **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides helophilus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Europe **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Aphelenchoides limberi	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Europe, North America, Asia **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides minor	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** India **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides myceliophagus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** India **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Aphelenchoides neocomposticola	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** India **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Aphelenchoides parientinus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Europe **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides richardsoni	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** UK **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Aphelenchoides sacchari	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Europe, Australia **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides saprophilus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Europe **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides spinosus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR) **On pathway?** Germany, Australia **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Aphelenchoides subtenuis	Nematode (Mycophagous)	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Europe, Israel, Australia, India **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Non-Regulated (BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Aphelenchoides swarupi	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** India, Italy **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Aphelenchus avenae	Nematode (Mycophagous)	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Europe, Australia **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Ditylenchus destructor	Nematode (Mycophagous)	**In NZ?** Present (NZOR), Not listed (UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium, but considered less capable of destroying mushroom mycelium than *D. myceliophagus*	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Ditylenchus dipsaci	Nematode (Mycophagous)	**In NZ?** Present (NZOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Non-Regulated (BORIC) Regulated (UOR)	Woodhall *et al*. (2009)
Ditylenchus filimus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Canada **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Ditylenchus intermedius	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Europe, North America **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Ditylenchus myceliophagus J.B. Goodey, 1958	Nematode (Mycophagous)	**In NZ?** Present (NZOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Potentially very damaging – the only *Ditylenchus* species considered economically important in commercial mushroom production	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Ditylenchus valveus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** North America, Asia **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium	Potential Hazard	Woodhall *et al*. (2009)
Filenchus misellus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Asia **Introduction?** Means of movement likely to be similar to other nematodes e.g. In compost or phoretic (carried by other invertebrates) **Impacts?** Observed experimentally to eat mushroom mycelia.	Potential Hazard	Woodhall *et al*. (2009)
Paraphelenchus myceliophthorus	Nematode (Mycophagous)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** England, India, Bulgaria **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Mycelium.	Potential Hazard	Woodhall *et al*. (2009)
Acrobeloides apiculatus	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide (not UK) **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost.	Potential Hazard	Woodhall *et al*. (2009)
Acrobeloides buetschlii	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide (not UK) **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost.	Potential Hazard	Woodhall *et al*. (2009)
Bursilla spp.	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Reported as saprophytic in mushrooms compost but effect on yield uncertain.	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Caenorhabditis elegans	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** If the nematode establishes it can rapidly inhibit mycelial growth. Complex relationship with bacterial species, which in some instances results in abnormal flushing patterns and mushroom distortion.	Non-Regulated (BORIC)	Woodhall *et al*. (2009)
Mesorhabditis spp.	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Reported as saprophytic in mushrooms compost but effect on yield uncertain.	Potential Hazard	Woodhall *et al*. (2009)
Panagrolaimus rigidus	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost.	Potential Hazard	Woodhall *et al*. (2009)
Pellioditis sp.	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** In compost or phoretic (carried by other invertebrates) **Impacts?** Reported as saprophytic in mushrooms compost but effect on yield uncertain.	Potential Hazard	Woodhall *et al*. (2009)
Pelodera (Cylindridera) icosiensis	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** China **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Reported with mushrooms but effects uncertain	Potential Hazard	Woodhall *et al*. (2009)
Pelodera lambdiensis	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** USA, Australia, Fiji and North Africa **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Vector of bacterial diseases of mushrooms	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Pelodera strongyloides	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost	Potential Hazard	Woodhall *et al*. (2009)
Prodontorhaditis sp.	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** China **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Reported to have a harmful effect – no further details	Potential Hazard	Woodhall *et al*. (2009)
Rhabditella spp.	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Reported as saprophytic in mushrooms compost but effect on yield uncertain	Potential Hazard	Woodhall *et al*. (2009)
Rhabditis (Cephaloboides) oxycera	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Not known **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost.	Potential Hazard	Woodhall *et al*. (2009)
Rhabditis (Choriorhabditis) longicaudatus	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Not known **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost.	Potential Hazard	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Rhabditis (Pellioditis) pellio	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide (not UK) **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost.	Potential Hazard	Woodhall *et al*. (2009)
Rhabditis cucumeris	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Worldwide (not UK) **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Can suppress the development of mushroom mycelium, bacterivorous nematode possibly an indirect affect.	Potential Hazard	Woodhall *et al*. (2009)
Rhabditis terricola	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Not known **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Indirect effect on mushroom production – either through the release of toxins into the compost or facilitating the rapid and thorough bacterial colonisation of the compost.	Potential Hazard	Woodhall *et al*. (2009)
Trilabiatus sp.	Nematode (Saprophytic)	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** China **Introduction?** Passive dispersal, survival in compost or phoretic on flies. Possibly distributed by air currents when in a dried state. **Impacts?** Reported with mushrooms but effects uncertain.	Potential Hazard	Woodhall *et al*. (2009)
Badhamia utricularis (Bull.) Berk.	Slime mould pathogen on Mushrooms	**In NZ?** Present (NZOR), Not listed (BORIC/UOR) **On pathway?** Present on a wide range of hosts and habitats worldwide **Introduction?** In compost **Impacts?** Potentially causes chocolate brown patches on mushroom	Potential Hazard (probably not a hazard)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Agaricus bisporus Endornavirus 1	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Part of the MVX complex found in Europe. **Introduction?** Associated with fungi. **Impacts?** Sporadic infections. Possibly no symptoms in isolation from other viruses.	Potential Hazard	Woodhall *et al*. (2009)
Agaricus bisporus Mitovirus 1 (AbMV1)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus Spherical Virus (AbSV)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 10 (syn. Mushroom virus 10)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 11 (syn. Mushroom virus 11)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 12 (syn. Mushroom virus 12)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 13 (syn. Mushroom virus 13)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Agaricus bisporus virus 14 (syn. Mushroom virus 14)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 15 (syn. Mushroom virus 15)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 2 (syn. Mushroom virus 2)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Possibly wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts** Mushroom growth	Non-Regulated (BORIC)	BORIC (Accessed October 2016) Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 3 (syn. Mushroom virus 3)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Possibly wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts?** Mushroom growth	Non-Regulated (BORIC)	BORIC (Accessed October 2016) Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 4 (syn. mushroom virus 4)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Possibly wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts?** Mushroom growth	Non-Regulated (BORIC)	BORIC (Accessed October 2016)
Agaricus bisporus virus 5 (syn. Mushroom virus 5)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Possibly wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts?** Mushroom growth	Non-Regulated (BORIC)	BORIC (Accessed October 2016) Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 6 (syn. Mushroom virus 6)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Associated with Brown Cap Mushroom Disease.	Potential Hazard	Fleming-Archibald *et al*. (2015)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Agaricus bisporus virus 7 (syn. Mushroom virus 7)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 8 (syn. Mushroom virus 8)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Agaricus bisporus virus 9 (syn. Mushroom virus 9)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Unknown. **Introduction?** Associated with fungi. **Impacts?** Unknown.	Potential Hazard	Fleming-Archibald *et al*. (2015)
Brown Cap Mushroom Virus (syn. *Agaricus bisporus* virus 16) Brown Cap Mushroom Disease	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Europe (same as MVX). **Introduction?** Associated with fungi. **Impacts?** Causes Brown Cap Mushroom Disease. Associated with MVX disease.	Potential Hazard	Fleming-Archibald *et al*. (2015)
La France Isometric Virus (LIV) (syn. *Agaricus bisporus* virus 1)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR), Recorded in New Zealand (pers. com. industry). **On pathway?** Wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts?** Die back, yield loss, drumstick shaped mushrooms, discolouration.	Potential Hazard (Regulated BORIC/UOR)	Woodhall *et al*. (2009)
Mushroom 18nm isometric virus	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Possibly wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts?** Mushroom growth	Potential Hazard (Regulated BORIC)	BORIC (Accessed October 2016)
Mushroom bacilliform virus (MBV)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Probably wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts?** None. Usually occurs with LIV.	Potential Hazard (Regulated BORIC)	Woodhall *et al*. (2009)

Organism name	Type/Host(s)	Hazard assessment	Hazard status	Reference(s)
Mushroom virus X (complex)	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/UOR) **On pathway?** Contaminates fungi in Phase 3 compost **Introduction?** Easily contaminates facilities and equipment **Impacts?** Causes significant mushroom production losses. Bare patches on beds; brown caps.	Potential Hazard (Regulated BORIC)	Largeteau *et al*. (2010) Sanchez (2010) Woodhall *et al*. (2009)
Vesicle virus	Viral Pathogen of Mushrooms	**In NZ?** Not listed (NZOR/BORIC/UOR) **On pathway?** Probably wherever mushrooms are grown. **Introduction?** Associated with fungi. **Impacts?** None.	Potential Hazard	Woodhall *et al*. (2009)

References for Appendix

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