Project title	Developing alternatives to peat in casing materials for mushroom production
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Project leaders:	Dr Ralph Noble
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Key staff:	Andreja Dobrovin-Pennington
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DISCLAIMER

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GROWER SUMMARY

Headline

Mushroom yields and quality from casing prepared from rewetted blocking peat and milled peat fines were comparable with those from wet dug peat casings. The incidence of bacterial blotch and the population of blotch causing *Pseudomonas tolaasii* were reduced by the use of the blocking peat casing or by the addition of 25% bark fines to wet dug peat casings.

Background and expected deliverables

Previous research has shown that the most promising peat substitutes in mushroom casing are composted bark fines, mature green waste compost, recycled casing, recycled granulated waste rockwool slabs and filter cake clays. Coir was incorporated into some commercial blends for several years but it is no longer used due to the increased demand and cost of the raw material, particularly for uses such as strawberry grow bags. However, spent coir is a significant disposal problem for the soft fruit industry. In this project, the effect of using the above materials individually and in combinations of materials will be investigated. The specific objectives of the project are:

1. To update and summarise any more recent information on peat alternatives in casing published since HDC project M 53
2. To produce data that meets the requirements of EA low risk waste status and/or food safety regulations
3. To undertake commercial farm trials with the five most promising alternative materials identified from small-scale experiments in M 38 and M 53
4. To test how experimental physical, chemical and microbial standards for casing materials relate to mushroom yield, quality and blotch incidence on commercial farms
5. To electronically monitor crop water management and casing water status, and determine how these interact with the performance of casing materials and the occurrence of blotch
6. To communicate and disseminate results to industry
7. To monitor industry uptake of peat substitute casing materials.

Summary of the project and main conclusions

Discussions with several European casing manufacturers has shown that decreasing availability of wet dug peat for mushroom casing is a problem not only in Britain but also in the Netherlands and Belgium. Other types of peat and peat production by-products are available in Britain in sufficient quantities to supply the mushroom industry. A review of potential alternatives to wet dug peat has shown that the most promising peat alternatives were composted bark fines, granulated recycled rockwool slabs, spent coir from grow bags, PAS 100 green waste compost, and filter cake clays.

The main conclusions from mushroom cropping trials conducted at three farms were:

1. Mushroom yields and quality from an Everris casing prepared from dried blocking peat and milled peat fines were similar to Harte and Topterra wet dug peat casings.
2. Addition of 25% bark slightly improved yield from Harte casing at Farm A, but reduced yield in Harte casing at Farm B and in Everris and Topterra casings at Farms A and C. This was probably due to insufficient water being added to the latter casing mixes.
3. The effect of addition of 25% recycled rockwool at all three farms and in all three types of peat casing was not significant compared with the respective peat control casings.
4. Filter cake clay added at 20% in peat casing reduced mushroom yield but the effect of 12.5% clay was not significant.
5. Green waste compost was not a suitable casing ingredient at 25% inclusion rate due to reduced mushroom yield; spent coir was unsuitable because it encouraged green mould.
6. At one farm, bacterial blotch occurred on mushrooms grown on Topterra casing, with or without 25% recycled rockwool, but not on Topterra casing containing 25% bark or on Everris blocking peat casing.
7. The occurrence of blotch on different casings corresponded with populations of *Pseudomonas tolaasii* determined from a Taqman PCR test on the casing materials at the end of the second flush.

Financial benefits

The results to date have shown that casing prepared from dried blocking peat and milled peat fines, and rewetted before use, can produce comparable mushroom yields and quality to casing prepared from wet dug peat. Due to availability in Britain and reduced transport costs of dried materials, this could potentially result in a lower cost casing than casing prepared from wet dug peat. There is potential for suppressing bacterial blotch by controlling the type of peat and additives such as bark fines that are added to casing.

Action points for growers

None at this stage.

SCIENCE SECTION

Introduction

Commercial and scientific developments that have occurred in peat substitution since M 55

Previous HDC funded research in project M 38 and a subsequent review in project M 55 showed that the most promising peat substitutes in mushroom casing were coir, composted bark fines, green waste compost, recycled casing and recycled granulated waste rockwool slabs. Coir was incorporated into some commercial blends for several years but it is no longer used due to the increased demand and cost of the raw material, particularly for uses such as strawberry grow bags. However, about 20,000 cubic metres of spent coir are discarded annually from the soft fruit industry and this is a potential source of material for mushroom casing. Bark was not taken up commercially due to cost. However, composted bark fines (the most suitable grade for casing) are now more available (Melcourt) and large supplies of aged bark are available in Scandinavia (Lindum). Small-scale experiments in M 53 also showed that it could be used beneficially in peat-based casing at 25% v/v. Increased cost of landfill disposal of used rockwool slabs means that granulating for re-use is now a cheaper option (Grodan, Cultilene).

Sturgeon (2011) reported on the use of composted green waste in casing. Cropping results with proportions of green waste compost in casing in project M 53 were variable, although cropping results with one source of matured compost used at up 25% by volume with Everris casing were comparable with yields from the control Everris casing. The variability in mushroom yield obtained from different sources of green waste compost was not explained by differences physical or chemical properties such as electrical conductivity. As with SBL used in casing (Visscher 1988), it is likely that maturity and stability of green waste compost are important characteristics. Due to the abundance (>4 million m^3), local availability and relatively low cost of green waste compost, identifying suitable sources and desirable characteristics of the material, would be worthwhile, even for low inclusion rates in mushroom casing.

Following research conducted at HRI in the 1990s, multi-roll filter cake (MRF), a clay filter-cake by-product from the coal mining industry was developed as a commercial casing ingredient by Tunnel Tech-ECB and used by several mushroom farms for over six years. The development achieved a ‘Science into Practice Grower of the Year Award’ for TT in 2005. However, new EA waste legislation prevented the use of MRF in mushroom casing from 2008 until the material was granted a low risk waste exemption in 2012. The increase in sand and aggregate washing plants means that similar clay-like filter cakes are now more widely available than MRF. Pale colour, low cost and proximity to casing production means that these filter cakes are more attractive as a casing ingredient than MRF. Due to similar water holding characteristics, filter-cakes and mature composts also have the potential to replace SBL, a significant cost component in casing. The decline in the sugar industry in Britain and Ireland means that there is less SBL available and transportation distances to casing production has increased. Results from small-scale experiments in M 53 showed that a combination of a dense material (filter-cake) and a light material (used rockwool) performed better as a casing peat substitute than the individual materials.

Other materials that have been tested for use as casing materials for cultivation of *Agaricus bisporus* or *Agaricus blazei* in recent years include leached sugarcane bagasse (Booyens 2012; van Rooyen 2012), subsoil and charcoal (De Siqueira et al 2009; Coluato et al 2011), lime schist (Colauto et al 2010), composted vine shoots (De Juan et al 2003; Pardo et al 2003) and vermicompost (Garcia et al 2008; Zakaei et al 2013). However, cropping results were generally inferior to those obtained from peat casing.

In Britain, supplies of wet dug peat are no longer available and all wet dug peat casing is imported from Ireland, Belgium and the Netherlands. However, black peat for blocking composts, milled brown peats and by-product peats are still available in sufficient quantity to supply the British mushroom industry. Unlike wet dug peat, these other sources of peat are partially dried during harvesting and processing, and therefore require rewetting before use as mushroom casing. Casing producers in the Netherlands are currently examining increasing the proportion of blond peat (which is still widely available) and reducing the quantity of black peat (which is becoming scarcer).

Developments in the recycling of spent casing, particularly in the Netherlands

There has been a large amount of research into using spent mushroom compost (SMC) for re-use in casing, most recently by Barry et al (2008) who demonstrated a clear negative effect on yield. This effect was alleviated by leaching but this is not a practical solution in the UK. More promising has been the re-use of separated spent casing (Nair & Bradley, 1981). Farsi et al (2011) removed casing from compost using a perforated plastic mesh inserted between the compost and casing layers at filling. This had no effect on mushroom yield. Recycled casing was composted for 3 weeks and then leached. Mushroom yield from the recycled casing was not significantly different to that from fresh casing.

MushComb in the Netherlands have developed a machine for separating the casing from the compost on emptying shelves. Oei (2011) states that by using this technology, 50-75% of casing can be recycled with only a 5-10% reduction in yield compared with using fresh casing. Experiment results in project M 53 have shown that 25% v/v can be recycled without a mushroom yield penalty.

Fig. 1. MushComb casing separator in use at a shelf farm in the Netherlands

Changes in the legislation affecting the use of different raw materials in growing media

PAS100 composts are marketed as soil amendments and are not classified by the EA as wastes. Multi-roll filter cake has a low risk waste exemption for use in mushroom casing by the Environment Agency (EA). Spent compost or casing recycled on-site in new casing would be exempt from waste regulations, other than storage limits. Spent mushroom compost also has a low risk waste exemption but there is a restriction in quantity of 50 tonnes on-site before bagging. Used rockwool is classified as a waste; it currently has a low risk status waste exemption for re-use in the production of new rockwool growing slabs. It does not yet have this exemption for use in a mushroom casing material. Spent coir from strawberry grow bags would also be classed as a waste. Analysis of these spent materials and mushrooms grown on them for pesticide residues and heavy metals would be needed to achieve a waste exemption for use in mushroom casing from the EA.

Defining the properties of the optimum casing material

There are currently no parameters for defining the properties of the best peat or peat substitute casings. Increasing salt content or electrical conductivity of casing has generally been found to reduce mushroom yield; this was confirmed in HDC project M 53. Previous work has found conflicting evidence for the importance of water and air holding characteristics of casing materials for mushroom yield. Project M 53 found that the Air Filled Porosity (AFP) of a casing material explained 50% of its cropping potential, with an optimum

AFP value of about 19% v/v. Coluato et al (2010) found that the yield of *Agaricus blazei* was optimum when the proportion of microporosity in a casing was 49 to 55% of total porosity (microporosity was defined as the volume of water retained divided by the drainage water from a sample). Zied et al (2011) found that the yield of *Agaricus blazei* correlated positively with the water holding capacity and negatively with bulk density of ten different soils used for casing but there was no effect of casing porosity on mushroom yield. Rangel et al (2008) measured the porosity and water holding capacity of different casing materials but no clear relationship with mushroom yield was found.

Improved control of water management and blotch using different casings

In project M 35, the availability of water from peat casing was measured electronically using tensiometers which record the water tension (matric potential) on a data logger. Watering patterns on different farms and in different crops and casings were monitored with electronic tensiometers. Periods with over-wet or dry casing were detected from the graphical output of the tensiometer data and related to cropping problems and the occurrence of water stress symptoms such as watery flesh, distorted caps or leggy stems. Watering regimes on mushroom farms are often aimed at bacterial blotch prevention rather than maximising mushroom yield. Data from electronic tensiometers should enable the water requirements of the mushroom crop grown with different casing materials to be more precisely controlled.

Previous work has shown that casing materials differ in the populations of pseudomonad bacteria present, and there is a large increase in the casing population during the life of a crop (Noble et al. 2003, 2009). However, it is not known what proportion of the pseudomonads cause blotch. A real time PCR diagnostic test for mushroom blotch pathogenic *Pseudomonas tolaasii* has been developed in project M 54. The test can distinguish bacterial blotch causing strains from other pseudomonads in pot experiments using introduced inoculum. Although ginger blotch causing strains are not distinguished, this is not currently regarded as a significant cause of crop loss. The diagnostic test can potentially be used on commercial casing materials to determine the risk from blotch if conditions are also conducive. It is well established that amendment of peat growing media with organic amendments such as bark and composts can suppress soil-borne plant pathogens (Noble & Coventry, 2005), although the effect of casing amendments on the occurrence of bacterial and fungal mushroom pathogens is unknown.

Materials and methods

General cropping procedure

Cropping trials were conducted at Chelbury Mushroom Farm, Gloucs., Flixton Mushrooms, Norfolk and Little Hall Farm, Lancs. A further cropping trial at Chelbury Mushroom Farm is currently in production.

Compost spawn-run with the strain A15 was filled into wooden cropping trays (Table 1). Spawn-run compost (caccing) or Casing Inoculum (CI) was mixed into wetted casing materials (Table 1). Casings were applied to trays to a depth of 50 mm. The trays were stacked five high. The trays were watered after application, at two-day intervals until airing, after the first mushrooms were about 15 mm diameter, and after the first and second flushes of mushroom were picked. The water application in the initial mixing of the casings, and watering after application of the casings to the cropping trays was adjusted to maintain a moisture content of about 6% v/v below the water retention after drainage from saturation. The air in the cropping rooms was recirculated and the relative humidity maintained at 95 - 98% until mycelial growth in the casing layer had become established, about 6 days after application. Fresh air was then introduced into the growing room and the relative humidity reduced to 88 - 91%.

Mushrooms were mainly picked with the veils closed at a diameter of 35 – 45 mm, over a 23 day period (three flushes) with the first flush being picked c. 17 days after the application of the casings. The weights of small buttons (<35 mm diameter), large buttons (>35 mm) and open mushrooms were recorded daily. The appearance of blotch, green mould and other diseases was recorded.

Table 1. Tray size and compost fill at different farms.

Farm	Tray area, m^2	Compost/tray kg	Caccing or CI per m^3 casing	Casing L/m^2
A	0.93	90 (Phase II)	CI, 2 L	54
B	2.4	300 (Phase II)	CI, 0.97 kg	54
C	2.3	180 (Phase III)	caccing, 6.3 kg	54

Casing treatments

The following casing materials were used as peat substitute materials:

(a) Growbark Pine, Melcourt Industries Ltd., Tetbury, Gloucs.

(b) Green waste compost (GWC), PAS 100 standard, composted and matured for at least 6 months, White Moss Horticulture, Kirkby, Liverpool, Merseyside.
(c) Used granulated rockwool slabs (obtained from cucumber and tomato growers), composted for 6 months, Materialchange, Helmsden, Northants.
(d) Recycled, cooked-out separated spent mushroom casing
(e) Clay from sand quarries (Marshalls, Rawtenstall, Lancashire and Dewsbury, W. Yorks)
(f) Spent coir from strawberry grow bags (Hugh Lowe Farms, Kent and Haygrove Ltd, Herefords).

Peat substitute materials were tested in three peat + SBL casing materials (Table 2). Two of the peat-based casings were commercial products containing wet dug peat (Harte and Topterra) and when used alone or with 20% clay did not require wetting before application. The Everris casing consisted of 50% v/v blocking peat, 30% v/v milled peat fines and 20% SBL and required wetting before application (Table 2). All the other substitute materials used with Harte, Topterra or Everris casing required various quantities of water during mixing before application (Table 2).

The quantities of water added to each mix at each farm are shown in Table 2. The non-amended Harte and Topterra casings prepared from wet dug peats required little or no water during mixing. Where substitute materials, except clay, were added to these casings, additional water needed to be added during mixing. Everris casing prepared from partially dried peats required wetting during mixing, irrespective of whether substitute materials were added. In each experimental crop, three replicate trays of each treatment were prepared, with the three replicates positioned in different stacks and layers.

Table 2. Casing treatments used at farms A, B and C, and volume of water added at mixing. C1 and C2 refer to two crops grown at Farm C.

Casing substitute,	Peat + Sugar beet lime casing, litres water/m^3 casing		
% v/v	Harte	Everris	Topterra
Control, none	**A, B, C2** 0, 9, 0	**A, C1, C2** 129	**C1, C2** 0
Bark, 12.5	-	**C2** 129	**C2** 66
Bark, 25	**A, B** 16, 59	**A** 118	**C1** 66
GWC, 25	**A** 21	**A** 118	-
Spent casing, 25	**A** 18	**A** 118	-
Spent coir, 25	**A, B** 41, 51	**A** 94	**C1** 59
Recycled rockwool, 25	**A, B** 53, 133	**A, C1** 129	**C1** 81
Clay, 12.5	-	**C1** 133	-
Clay, 20	**B** 0	-	-

Bark 12.5 + Clay 12.5	-	**C2** 129	-

- Indicates that the treatment combination was not examined.

Measurement of casing water tension

The availability of water from the casing was measured electronically using tensiometers which measure the water tension (matric potential) on a continuous basis using data loggers. Miniature tensiometers (type SWT5, Delta-T Devices Ltd, Cambridge) were positioned in the casing layers at the time of casing application. The matric potential of the casings were continuously recorded on a data logger (type DL2e Delta-T).

Properties of casing materials

Samples of casing (three 200 g samples from different trays of each treatment) in each test crop were analysed for gravimetric moisture content.

The following physical and chemical analyses were conducted on the peat + SBL casing samples and alternative materials before and after mixing: AFP, compacted bulk density, pH and EC (Noble & Dobrovin-Pennington, 2012). AFP was measured using two different methods, described in HDC report M 35. These are based on the volume of drainage water from a saturated sample, and on the fresh and dry weights of a saturated and drained sample, and a formula based on the density of organic matter in peat. The water holding capacity after free drainage in a 'Campot' test cylinder was determined according to HDC Report M 35.

Evaluation of a real-time PCR test for detection of Pseudomonas tolaasii

Total *Pseudomonas* spp. and total bacteria in the casing materials were determined by plating casing suspensions on selective media (Elphinstone et al 2011).

The real-time PCR test results for detection of *P. tolaassi* are given as Critical Threshold (CT) values (critical threshold at which amplification starts). DNA extracted from each sample was tested in duplicate. A CT of 40 indicates no amplification within the maximum number of 40 PCR cycles (i.e. a negative test). A CT value below 40 indicates amplification (a positive test) and the lower the CT the earlier amplification has started, indicating higher target DNA concentrations in the sample. As a general rule, a difference of 3 CTs represents a 10 fold difference in target DNA levels. In the test validation work in HDC project M 54, DNA extracted from a pure culture of *Pseudomonas tolaasii* containing around 10^8 cells per ml gave a CT value of around 19 - 22.

Residue and heavy metal analysis

Samples of peat + SBL casing (2), recycled rockwool (5) and spent coir (2), 500 g of each, were analysed by Groen Agro, Netherlands for pesticide residues using gas chromatography – mass spectrometry (GC-MS) and liquid chromotagraphy – mass spectrometry (LC-MS). Samples of first and second flush mushrooms (500 g) from two different crops were also analysed for pesticide residues.

Dried samples (100 g) of the above casing materials and mushrooms were also analysed for heavy metals by Groen Agro.

Results

This report presents data obtained in the first year of the project which has not yet been statistically analysed. A full statistical analysis of the data, including, where appropriate, comparisons of the same casing materials and blends in different crop experiments on the same farm and on different farms, will be presented in the final project report.

Analysis of casing materials

All the casing materials used in the experiments had a pH value of 6.94 to 7.68 and an electrical conductivity of 192 to 569 µS/cm.

Addition of the substitute materials to peat-based casing generally reduced the water volume retained after drainage of a saturated sample (Table 3) and increased the volume of water that drained out (Table 4). However, these effects were small and there were exceptions to these general statements. Adding 25% bark to Harte casing at Farm A or to Topterra casing at Farm C had no effect on the volume of water retained after saturation. Addition of green waste compost at 25% reduced the water that drained out of saturated Harte or Everris casing samples.

Table 3. Water volume retained after drainage of a saturated sample, %v/v

Casing substitute,	Peat + Sugar beet lime casing				
% v/v	Harte		Everris		Topterra
Farm	A	B	A	C	C
Control, none	72.0	74.5	68.4	68.1	69.6
Bark, 25	72.1	71.1	64.1	-	69.9
GWC, 25	72.0	-	65.2	-	-
Spent casing, 25	69.1	-	69.1	-	-
Spent coir, 25	69.6	68.9	68.7	-	68.3

Recycled rockwool, 25	70.3	68.1	67.4	-	69.0
Clay, 12.5	-	-	-	65.1	-
Clay, 20	-	66.9	-	-	-

Table 4. Volume of drainage water after saturation, %v/v

Casing substitute,	Peat + Sugar beet lime casing				
% v/v	Harte		Everris		Topterra
Farm	A	B	A	C	C
Control, none	17.3	14.4	18.2	13.9	18.2
Bark, 25	15.3	16.7	20.6	-	18.4
GWC, 25	14.9	-	17.0	-	-
Spent casing, 25	18.1	-	16.0	-	-
Spent coir, 25	20.5	19.3	18.4	-	20.8
Recycled rockwool, 25	17.4	20.3	17.0	-	18.6
Clay, 12.5	-	-	-	10.5	-
Clay, 20	-	15.5	-	-	-

Spent coir added at 25% increased the air filled porosity (AFP) in Harte and Topterra casings but not in Everris casing (Table 5). Clay added at 12.5% to Everris casing reduced the AFP whereas clay added to Harte casing at 20% increased the AFP. Bark, spent casing, green waste compost and recycled rockwool had only small and inconsistent effects on the AFP of peat-based casing (Table 5). Addition of recycled rockwool or clay to peat-based casing increased compacted bulk density (Table 6). Addition of bark, spent coir, spent casing or green waste compost had only small and inconsistent effects on compacted bulk density of casing.

Table 5. Air-filled porosity of casing materials, %v/v.

Casing substitute,	Peat + Sugar beet lime casing				
% v/v	Harte		Everris		Topterra
Farm	A	B	A	C	C
Control, none	20.4	17.8	22.9	20.9	22.5
Bark, 25	20.0	20.4	26.5	-	21.6
GWC, 25	19.0	-	23.2	-	-
Spent casing, 25	23.2	-	22.1	-	-
Spent coir, 25	23.1	23.6	22.8	-	24.2
Recycled rockwool, 25	21.3	22.8	22.1	-	21.5

Clay, 12.5	-	-	-	18.3	-
Clay, 20	-	18.3	-	-	-

Table 6. Compacted bulk density, g/L

Casing substitute,	Peat + Sugar beet lime casing				
% v/v	Harte		Everris		Topterra
Farm	A	B	A	C	C
Control, none	653	654	710	631	629
Bark, 25	631	684	625	-	650
GWC, 25	697	-	710	-	-
Spent casing, 25	621	-	666	-	-
Spent coir, 25	648	674	664	-	631
Recycled rockwool, 25	698	727	689	-	709
Clay, 12.5	-	-	-	720	-
Clay, 20	-	758	-	-	-

Mushroom yields, quality and disease incidence

Mushroom yields and quality from an Everris casing prepared from dried blocking peat and milled peat fines were similar to Harte and Topterra casings prepared from wet dug peats (Table 7). The addition of 25% green waste compost to Harte or Everris casing at Farm A reduced mushroom yield (Table 7). The effect of addition of 25% recycled rockwool at all three farms and in all three types of casing was not significant compared with the respective control casings. Addition of 25% bark slightly improved yield from Harte casing at Farm A, but reduced yield in Harte casing at Farm B and in Everris and Topterra casings at Farms A and C. This may have been due to insufficient water being added during the initial blending of the latter casing materials, as discussed in the following sections on casing moisture. At Farm A, spent casing at 25% reduced yield in Everris casing but not in Harte casing. Spent coir resulted in green mould (*Trichoderma harzianum*) in Harte casings at Farm B and in Topterra casing in Farm C (data not shown). Clay at 20% reduced yield from Harte casing at Farm B but the effect of 12.5% clay in Topterra casing at Farm C was not significant.

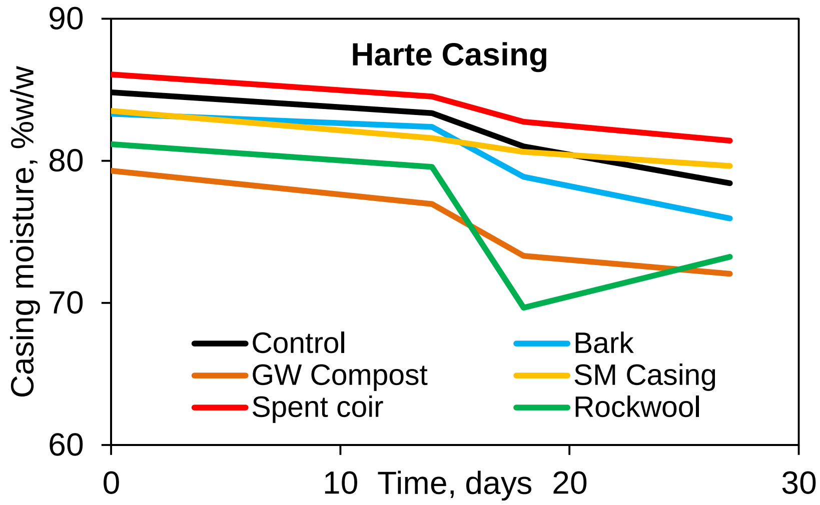
At Farm C, bacterial blotch was observed on all three trays cased with unamended Topterra casing, or Topterra casing containing 25% recycled rockwool. No blotch was observed in the Everris casings or in Topterra casing containing 25% bark. Blotch was observed on one out of three trays cased with 25% spent coir.

Table 7. Mushroom yields from different casing treatments at three farms, kg/m^2.

Casing substitute,	Peat + Sugar beet lime casing				
% v/v	Harte		Everris		Topterra
Farm	A	B	A	C	C
Control, none	28.5	32.3	30.1	30.6	30.6
Bark, 25	29.7	29.8	25.6	-	27.7
GWC, 25	25.3	-	28.6	-	-
Spent casing, 25	29.5	-	26.7	-	-
Spent coir, 25	29.5	28.4	27.5	-	25.2
Recycled rockwool, 25	29.2	32.1	29.8	-	29.6
Clay, 12.5	-	-	-	29.6	-
Clay, 20	-	28.0	-	-	-

Casing moisture content during cropping

The initial gravimetric moisture content of the peat-based control casings was generally between 81 and 85% w/w, although the initial moisture content of the Everris casing at Farm C was lower because it was not wetted up sufficiently. Differences in casing moisture content and water tension during cropping were observed between Farms A, B and C. Casing moisture content declined during cropping at Farms A and B (Figs. 2 and 3) whereas at Farm C, the moisture content only declined after the beginning of the first flush (Fig. 4). The gravimetric moisture contents of Everris casings were lower than equivalent treatments (unamended or 25% substituted) in Harte or Topterra casing (Figs. 2 and 4).The moisture contents of peat-based casing and casing containing 25% spent coir or recycled spent casing during cropping were similar (Figs. 2, 3 and 4). Casing containing 25% bark had a slightly lower moisture content than the control casing. Addition of 25% recycled rockwool or green waste compost or 12.5% clay to casing reduced the gravimetric moisture content of the casing during cropping, at least partly due to the higher bulk densities of these materials compared with peat.



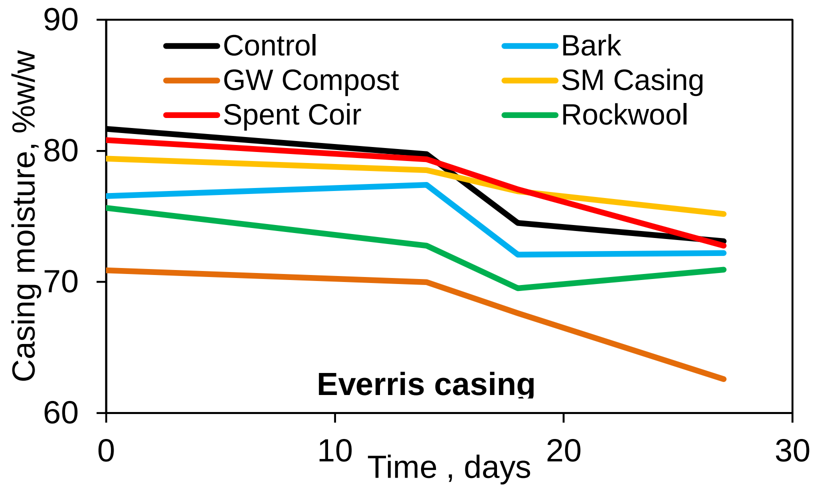


Fig.2. Moisture content of Harte and Everris casings containing 25% v/v of different substitute materials during cropping at Farm A.

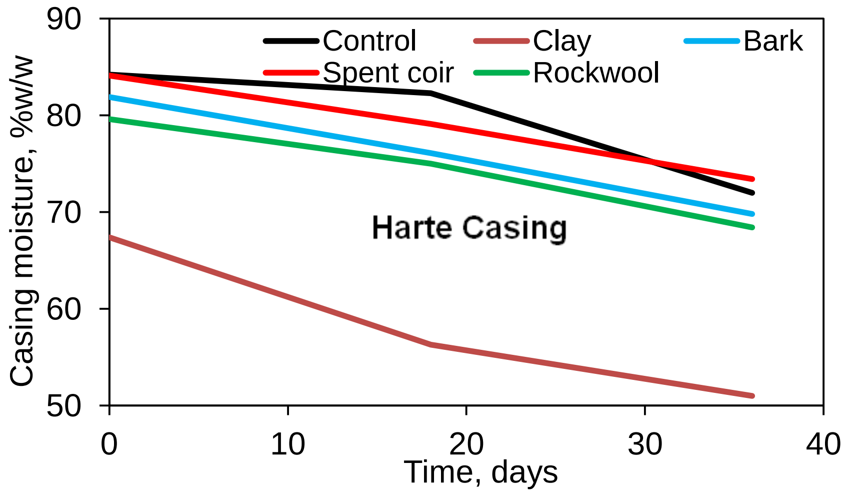


Fig.3 Moisture content of Harte casing containing 25% v/v of different substitute materials (or 20% clay) during cropping at Farm B.

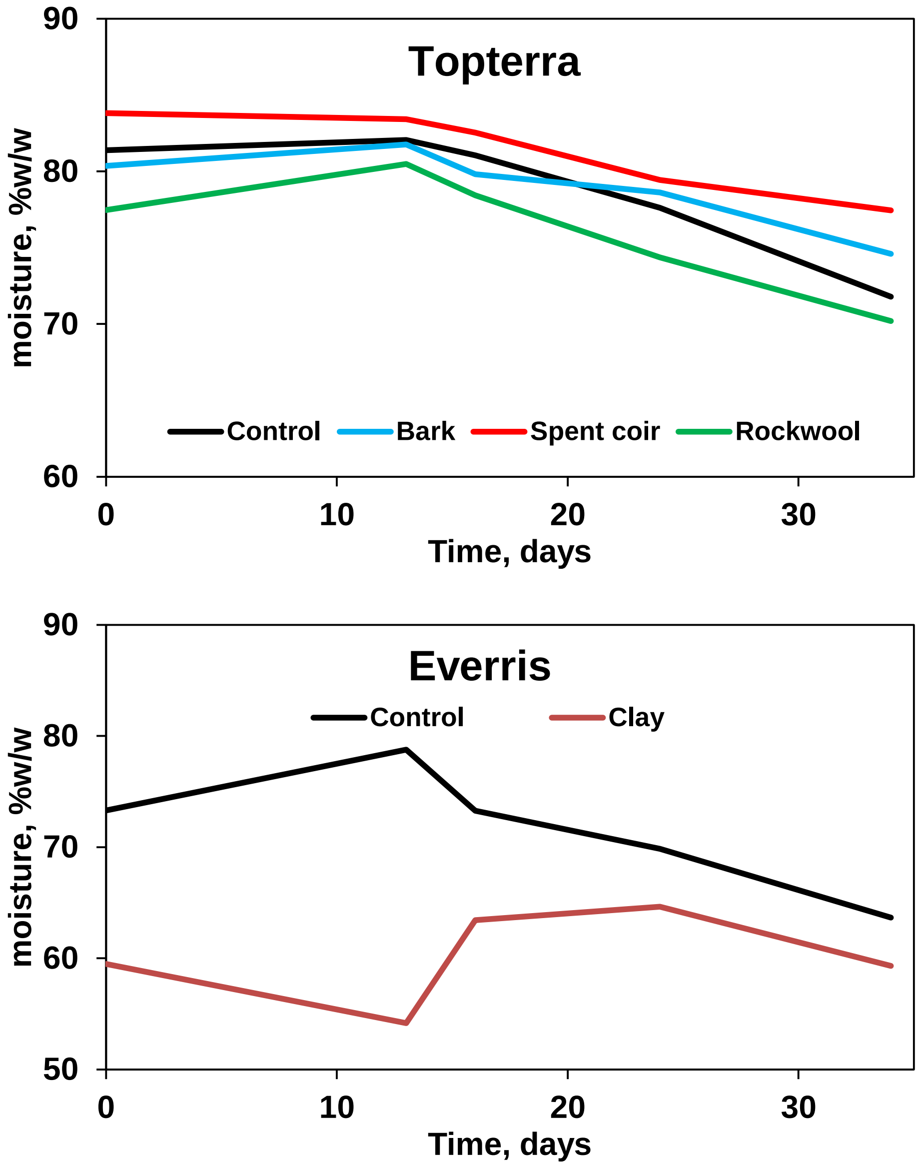


Fig. 4. Casing moisture of Topterra casing containing 25% of different substitute materials or Everris casing with and without 12.5% clay during cropping at Farm C.

Casing water tension during cropping

Casing water tensions before the first flush were small in all three farms, and the casing water tension in the first flush was always smaller than in the second flush (Figs. 5 to 8). The casing water tensions in the first and second flushes at Farms A and B were similar (Figs. 5, 6 and 7) whereas the water tensions at Farm C were much larger (Fig. 8).

At Farm A, casing water tension was slightly greater in the non-amended Everris casing than in Harte casing (Figs. 5 and 6). At Farm C, casing water tension was greater in the non-amended Everris casing than in the Topterra casing (Fig. 8). As mentioned previously, this was due to insufficient water being adding during mixing. Addition of substitute materials at

25% to casing generally reduced the water tension during the first and second flushes compared with the unamended peat-based control casings (Figs. 5 to 8). Exceptions were addition of 25% bark to casing at Farms A and C (Figs. 5 and 8) and 25% spent coir at Farm B (Fig. 7).

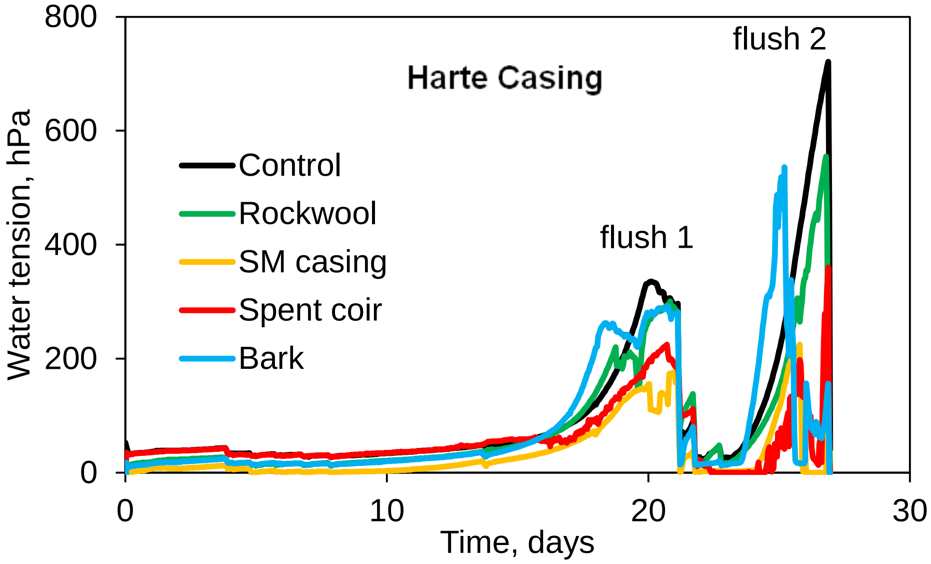


Fig. 5. Water tension in Harte casing containing 25% v/v of different materials during cropping at Farm A.

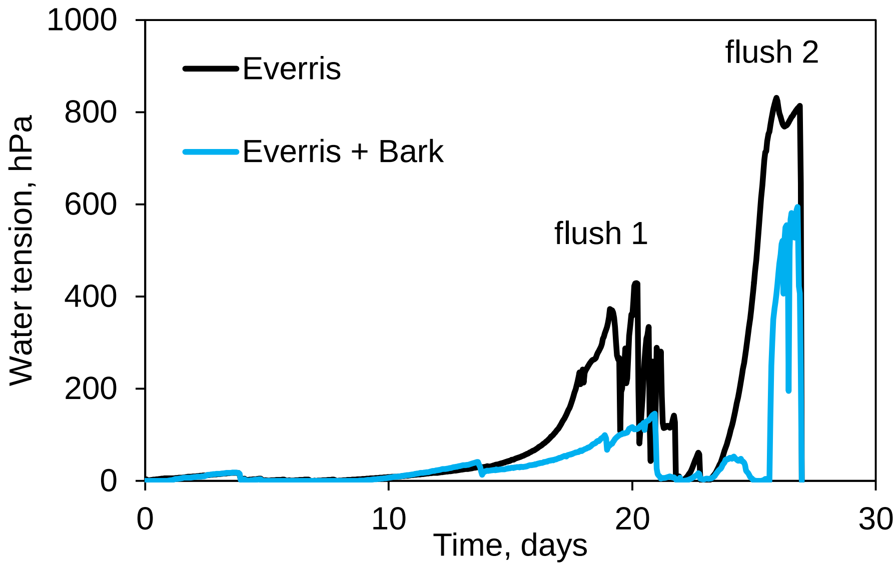


Fig. 6. Water tension in Everris casing with and without 25% v/v bark during cropping at Farm A.

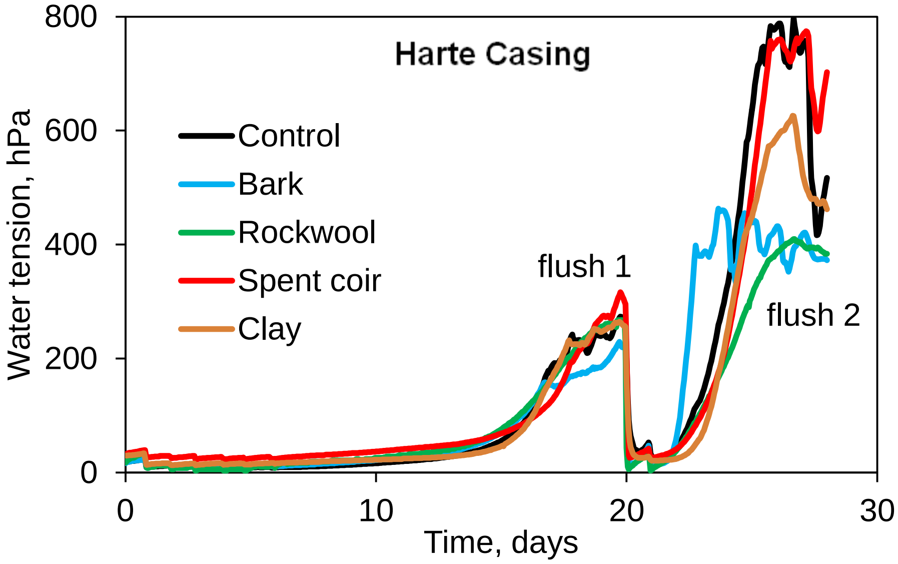


Fig. 7 Water tension in Harte casing containing 25% v/v of different substitute materials (or 20% v/v clay) during cropping at Farm B.

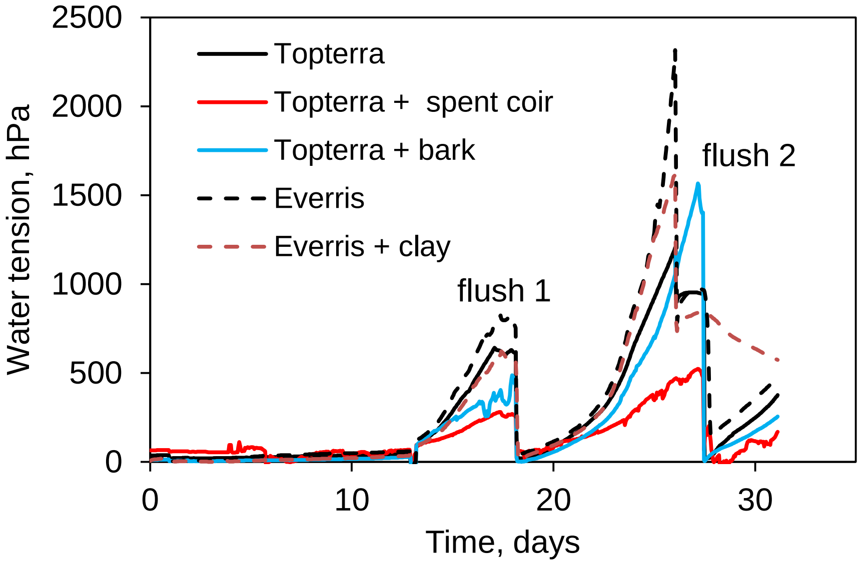


Fig. 8 Water tension in Topterra casing containing 25% v/v of different substitute materials or Everris casing with and without 12.5% v/v clay during cropping at Farm C.

Evaluation of a real-time PCR test for detection of Pseudomonas tolaasii

All the fresh samples of casing materials used at Farm C had a CT value of 40 indicating that the level of *P. tolaasii* was below the detectable limit. At the end of the second flush positive values were found with differences apparent between casing materials (Table 8). The lowest CT values (and therefore most positive for *P. tolaasii*) were found in Topterra casing, either unamended or with 25% recycled rockwool. Blotch symptoms were found on all three trays of these treatments. Conversely, no blotch was found on the Everris casings or Topterra casing containing 25% bark, which had higher CT values (and therefore less positive for *P. tolaasii*). A separate sample from a Topterra cased tray with blotch in the commercial section of the room had a CT value of 30.75.

Table 8. Taqman PCR *Pseudomonas tolaasii* CT results in casing after 2nd flush, Farm C. Each value is the mean of two test samples.

Casing substitute,	Peat + Sugar beet lime casing	
% v/v	Everris	Topterra
Control, none	37.21	29.68
Bark, 25	-	31.99
Spent coir, 25	-	31.72
Recycled rockwool, 25	-	26.50
Clay, 12.5	33.22	-

- Indicates treatment combinations that were not examined.

Fig.9. Severe bacterial blotch on mushrooms grown with Topterra casing at Farm C.

Residue and heavy metal analysis

Concentrations of heavy metals in filter cake clay were similar to those in peat + SBL casing, except chromium (Cr) which was higher in the peat-based casing, and copper (Cu) and (Zn) where higher values were obtained in the clay (Table 9). Values for arsenic (As), cadmium (Cd), and mercury (Hg) were lower in recycled rockwool than in peat + SBL casing, but values for cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni) and Zinc (Zn) were higher. However, all the heavy metal values in peat + SBL casing, filter cake clay and recycled rockwool were below the regulatory limit for land application for organic wastes, except nickel in one of the samples of recycled rockwool.

Heavy metal contents except copper and zinc were below detectable limits in all first and second flush mushrooms sampled (Table 10). Copper and zinc contents in mushrooms grown on peat + SBL, 25% recycled rockwool or 12.5% clay were similar, although the concentrations were consistently higher in the second flush than in the first (Table 6).

Table 9. Heavy metal analysis of casing ingredients; maximum and minimum values in three analyses, mg/kg dry weight.

Heavy metal	Peat casing		Recycled rockwool		Filter cake clay		Regulatory limit*
	Min.	Max.	Min.	Max.	Min.	Max.	
As	<0.4	0.9	-	<0.4	<0.4	0.9	5
Cd	<0.1	0.2	-	<0.1	-	<0.1	0.75
Co	-	<0.05	1.3	4.0	-	<0.05	75
Cr	<0.1	3.1	10	67	<0.1	1.1	70
Cu	<0.05	5.2	10	30	<0.05	9.1	70
Hg	<0.01	0.02	-	<0.01	<0.01	0.02	0.4
Ni	<1.0	1.1	5	50	<1.0	0.9	25
Pb	<0.1	0.6	<0.1	13	<0.1	0.5	45
Zn	<0.05	8.6	100	120	<0.05	66.7	200

* EU and UKROFS regulatory limits for composts applied to agricultural land (European Commission, 2004)

Table 10. Heavy metal analysis of mushrooms grown on peat/SBL casing and casings substituted with 25% recycled rockwool or 12.5% clay, and EU regulatory limit for mushrooms, mg/kg dry weight.

Heavy	Peat casing		Recycled rockwool		Clay		EU limit*
metal	1st	2nd	1st	2nd	1st	2nd	
As	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	-
Cd	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2
Co	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
Cr	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-
Cu	23.4 - 23.8	47.2 – 48.1	22.3	56.5	23.0	46.9	-
Hg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.3
Ni	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	-
Pb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3
Zn	40.6 - 43.5	70.5 - 74.2	46.7	81.9	45.3	70.9	-

* EU limit for Agaricus mushrooms (European Commission, 2001).

Trace levels of residues of several pesticides approved for tomatoes, cucumbers and strawberries were detected in the recycled rockwool and spent coir (Tables 11 and 12). Azoxystrobin, Bupirimate, Cyprodinil, Fludoxinil and Myclobutanil were detected in four out of five samples of recycled rockwool. All the other pesticides were only detected in one out of five samples. Boscalid, Dimethomorph, Myclobutanil and Penconazole were detected in both samples of spent coir tested. All of the pesticide residues detected were below the EU minimum residue limits (MRLs) for tomato fruit, except Fludoxinil and Myclobutanil in recycled rockwool and Quinoxfen in spent coir. However, all of the residue levels detected in the recycled rockwool and coir samples were below the MRLs for tomato fruit when used at 25% by volume in peat casing. No pesticide residues were detected in any of the first or second flush mushrooms grown on 25% recycled rockwool or 25% spent coir casings.

Table 11. Maximum and minimum pesticide residues detected by Groen Agro in five samples of granulated 6-month composted used rockwool slabs obtained from Grodan and Materialchange, and EU minimum residue levels in tomato fruit (mg/kg). Detection threshold was 0.01 mg/kg.

Pesticide	Detection method	Min	Max.	Positive samples	MRL tomato
Azoxystrobin	LC-MS	0.32	1.00	4	3.0
Boscalid	LC-MS	0.03	0.15	1	3.0
Bupirimate	LC-MS	0.12	0.42	4	2.0
Carbendazim	LC-MS	-	0.01	1	0.3
Cyprodinil	LC-MS	0.14	0.55	4	1.0
Fludioxonil	GC-MS	1.12	3.70	4	1.0
Imazalil	LC-MS	-	0.01	1	0.5
Imidacloprid	LC-MS	-	0.01	1	0.5
Iprodione	GC-MS	-	0.02	1	5.0
Metalaxyl	GC-MS	0.03	0.13	1	0.3
Myclobutanil	LC-MS	0.27	0.65	4	0.3

Table 12. Maximum and minimum pesticide residues detected by Groen Agro in two samples of used spent coir, and EU minimum residue levels in tomato fruit (mg/kg). Detection threshold was 0.01 mg/kg.

Pesticide	Detection method	Min	Max.	MRL tomato
Boscalid	LC-MS	0.04	0.23	3.0
Dimethomorph	LC-MS	0.09	0.30	1.0
Myclobutanil	LC-MS	0.14	0.15	0.3
Penconazole	GC-MS	0.01	0.04	0.1
Quinoxyfen	LC-MS	-	0.06	0.02

Discussion

This work has shown that a suitable mushroom casing can be prepared from black blocking peat and milled peat fines. However, unlike casing prepared from wet dug peat, this casing requires rewetting before use, although blocking peat readily absorbs moisture and does not require pre-soaking such as brown milled peats that were used for mushroom casing more than 20 years ago. For farms that no longer have casing mixers, some reinvestment would be required for such a casing to be used. However, there is a potential cost saving since the material is cheaper to transport due to lower water content and availability of materials in the Britain. Suppression of bacterial blotch is also a potential benefit of casing prepared from blocking peat.

Although the effect of adding 25% bark fines on mushroom yield was inconsistent between farms, the potential for suppressing bacterial blotch is being investigated further by using a lower (12.5% v/v) inclusion rate. The effect of adding 12.5% filter cake clay to casing on mushroom yield was not significant. The effect of combing this dense material with a more porous material (bark) is also being investigated in a current experiment.

Casing including 25% granulated recycled rockwool slabs produced mushroom yields comparable with peat casings at all three farms, and it did not stick to the mushrooms. However, it did not suppress bacterial blotch when added to Topterra casing. Although trace levels of approved pesticide residues were detected in the raw material, they were below the MRL for tomato fruit when used at 25% in casing and no pesticide residues were detected in the mushrooms. However, the material would require a waste license from the EA if used commercially for producing mushroom casing (it currently has an EA low risk waste exemption for re-use in growing slabs). In view of the limited supply of this material in Britain (about 8,000 cubic metres per year) it is only likely to be viable if the much larger quantities in the Netherlands and Belgium (around 60,000 cubic metres per year) are also available for use as mushroom casing. Discussions with Dutch and Belgian casing producers would establish if there is commercial interest in using recycled rockwool.

Mushroom yields using 25% spent casing were inconsistent between farms. It is only suitable if cooking out is used, and this is not practiced on all farms. Although machinery is available for separating casing on emptying in shelves, it is an expensive option and not suitable for tray farms. Due to the risk of disease spread and problems with weed moulds, casing producers do not want to receive this material and mixing on-farm would require additional equipment.

Conclusions

1. The supply of wet dug peat has been discontinued in Britain and dwindling supplies in Germany are also of concern to casing manufacturers in the Netherlands and Belgium.
2. Other types of peat and peat production by-products are available in Britain in sufficient quantities to supply the mushroom industry.

3. A review showed that the most promising alternatives to peat were composted bark fines, granulated recycled rockwool slabs, spent coir from grow bags, PAS 100 green waste compost, and filter cake clays.
4. Mushroom yields and quality from an Everris casing prepared from dried blocking peat and milled peat fines were similar to Harte and Topterra casings prepared from wet dug peats.
5. Addition of 25% bark slightly improved yield from Harte casing at Farm A, but reduced yield in Harte casing at Farm B and in Everris and Topterra casings at Farms A and C. This was probably due to insufficient water being added to the latter casing mixes.
6. The effect of addition of 25% recycled rockwool at all three farms and in all three types of casing was not significant compared with the respective peat control casings.
7. Recycling spent casing at 25% slightly improved yield at one farm but reduced yield at another.
8. Filter cake clay at 20% reduced mushroom yield but the effect of 12.5% clay was not significant.
9. Green waste compost was not a suitable casing ingredient at 25% v/v inclusion rate due to reduced mushroom yield; spent coir was unsuitable because it encouraged green mould.
10. At one farm, bacterial blotch occurred on mushrooms grown on Topterra casing, with or without 25% recycled rockwool, but not on Everris casing or Topterra casing containing 25% bark.
11. The occurrence of blotch corresponded with populations of *Pseudomonas tolaasii* determined from a Taqman PCR test on the casing materials at the end of the second flush.
12. Casing water tensions were consistently greater in the second flush than in the first flush at all three farms.

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