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Manufactured and Recycled Materials Used as Casing in (*Agaricus bisporus*) Mushroom Production

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ABSTRACT: Sphagnum peat moss has been the casing of choice for more than 20 years. In a search for alternative materials that would provide more benefits to mushroom farmers, three materials were identified that satisfy this need. One material, *RPC+*, a pelletted and roughened, recycled newspaper product, replaces peat moss. Two other materials, a mineral-based rockwool, *Capogro*, blended with peat moss at 40 to 60% (v/v) and Fly Ash, blended with peat moss at 25% (w/w). *RPC+* and *Capogro* support mushrooms with higher fresh-market quality. Irrigation and crop management regimes developed for sphagnum peat moss must be modified to maximize performance of the products. Handling and mixing the three products must also be changed to assure smooth mushroom farm operation. Two other products provide production that may equal that of sphagnum peat moss, but their availability is limited.

1 INTRODUCTION

Production systems for the button mushroom have included a top-dressing (casing) on fully colonized mushroom compost since the last century. Benefits of casing include: 1) it provides a surface on which uniform fructification can occur; 2) a reservoir of water for developing mushrooms; 3) the casing matrix supports the growth of bacteria considered important when fruiting is to be initiated; 4) casing limits the amount of water loss from mushroom compost; 5) casing changes the diffusion rate for metabolic gases, gases that influence primordium formation and mushroom growth.

Prior to 1966, mushroom farmers in Pennsylvania cased mushroom compost with clay-loam top soil that was steam pasteurized or fumigated. Between 1967 and the mid-1970s, a number of farmers used all or a proportion of weathered, spent mushroom substrate (SMS) as casing, Happ and Wuest, (1978). Since then, sphagnum peat moss has been the casing of choice.

Sphagnum peat moss rose to wide-spread usage as mushroom casing based partially on sound research by Flegg (1956) and Edwards and Flegg (1953), who evaluated peat moss as an alternative casing to mineral soil. However, factors other than mushroom yield influenced the decision to adopt peat moss as casing. Peat moss is available throughout the year, it rarely freezes solid, like soil, when stored at temperatures below 0°C, transportation and storage are convenient, its performance and handling are predictable, deep bog sphagnum peat moss rarely needs to be steam pasteurized before it is used, peat moss is packaged so one person can handle it, farmers perceive its benefits exceed its cost.

Notwithstanding the attractiveness of peat moss as mushroom casing, scientists in many nations have reported a wide variety of materials that might be used in place of peat moss (Stoller 1978, Yeo and Hayes 1978, Visscher 1988, Dergham *et al.*1990, Wuest and Muthersbaugh (1990), Noble and Gaze 1995, Labuschagne *et al.* 1995, Eicker and van Greuning 1989, Morris and Wuest 1995). Few of these alternatives have replaced peat moss as mushroom casing at mushroom farms.

This paper reports on the performance of five mushroom casing materials, three from the recycling stream and two manufactured mineral products.

2 MATERIALS AND METHODS

Cropping experiments for these casing material alternatives were conducted between 1988 and 1995 at the Mushroom Research Center and Mushroom Test Demonstration Facility, Department of Plant Pathology, The Pennsylvania State University.

2 *Recycled products*

Newspaper was the stock for *RPC+*, recycled newspaper that was fiberized and formed into roughened pellets. Glossy, colored advertisements were removed from the stock before *RPC+* was made. Phoenix Paper Products, Inc., Lostant, IL, provided a ready-to-use mushroom casing, one containing neutralizing agents. Other than neutralizing agents and water, nothing was added to the paper fibers during the pelleting process. *RPC+* readily absorbs water, it swells significantly when moistened, and it rewets easily after drying.

2.1.1 *Orfa Fiber* originated as household trash (domestic waste), products thrown away by householders and apartment dwellers. Industrial wastes were not included in *Orfa* fiber. Multiple truckload quantities of domestic waste were dumped at an *Orfa* processing plant in Philadelphia, PA. Glass and metal were removed, organic matter was treated with ozone for odor control, it was dried, ground and separated according to size. The material used for casing was in the shape of irregular, somewhat spherical, particles ranging in size from 7 to 16 mm (diam.), identified as *Orfa* Coarse Fiber. A fraction of smaller average size, 3 to 6mm, was identified as *Orfa* Fine Fiber.

2.1.2 *Fly Ash* is a high temperature residue formed during the coal combustion process and collected as a waste by-product. Coal combustion by-products are produced in many parts of Pennsylvania. Fly ash is currently combined with septage, sewage sludge, and mineral wool waste into synthetic soils used to revegetate surface-mine sites. Fly ash can be used as a fertilizer and a soil conditioner. Cement kiln dust is another waste product used as lime-potash fertilizer.

2.2 *Manufactured materials*

2.2.1 *Capogro*™ (medium size) is a mineral wool product spun from molten rock containing oxides of calcium 27%, silicon 43%, magnesium 12%, aluminum 10% and iron 4%, with a bulk density of 0.12g cc^{-1}. Its granulated appearance had an abrasive feel to it and its dust, when handled dry, caused some skin irritation. It had a total porosity of 95% compared to 89% for peat, 64% for perlite, and 74% for vermiculite. Air space was 30% with a capillary capacity of 49-63%, similar to peat moss. *Capogro* is easy to moisten, initially and after it has dried.

2.2.2 *Peatwool*™ was dark, dirty brown in color, abrasive to feel, and dusty to handle. It consisted of mineral fibers, 4.5-5.5 u diam., made from molten rock. Its chemical analysis includes oxides of silicon 42%, calcium 19-28%, magnesium 5-9%, and iron 10-16% (rockwool), plus 25% (v/v) sphagnum peat moss manufactured and formulated by Tetra, Inc., Elizabeth CO. *Peatwool*™ appears as irregular knots or curds, ca. 10-12mm diam., dark brown color, soft to touch, dusty when handled dry, and it is readily wetted when dry.

2.3 *Mushroom Research Center (MRC)*

Casing experiments were conducted on compost made from wheat-straw-bedded horse manure, chicken manure, dried brewers' grain and gypsum. Compost was prepared by a conventional 7 da Phase I and 7 da Phase II composting process. Each batch of compost was spawned with commercial spawn at the rate of 2%, wet wt/dry wt basis. Different compost supplements were mixed with compost, 4% (dry wgt/dry wgt), at spawning. Depending on the experiment, supplements used included Spawn Mate II SE (Spawn Mate, Inc., Capitola, CA), Fast Break (Penwest Foods, Co., Englewood, CO), and S-41 (Campbell's Full House, Napolean, OH). Spawned and supplemented compost was put into wooden trays, 122 x 122 x 15 cm [LxWxD] and firmly pressed to insure a level and uniform surface. Between 20.4 and 25 kg (45 and 55 lb) of wet compost was placed into each tray. Spawned compost was incubated for 13 to 17 da at 23 to 27C, in relative humidities above 88%.

Cac (compost added to casing) was mixed with the casing materials in some experiments. Either fully grown compost was cut into 0.8 to 3.2 cm pieces or commercial Cac, supplied by the spawn company, was mixed with each casing material at a rate equivalent to 0.45 kg per $0.93 m^2$ (1 lb per 10 ft^2). Casings for some experiments were pasteurized with steam for 1 to 2 hr at 60C a few days before it was needed, and before the Cac was added. Sphagnum peat moss served as a control in all experiments. Peat moss was mixed with agricultural, ground limestone at 22.7 kg per bale of peat (1 bag of limestone per bale of peat moss). The peat moss was wetted to a moderate level when limestone was mixed with it.

Each experiment was designed to provide 4 to 6 replicate trays for each treatment, with treatments located in a random design in a three trays high checkerboard layout in a growing room. Harvest data, yield and number, were recorded each day of picking. Picking occurred 7 da a wk, with mushrooms closed and the veil slightly stretched as criteria for harvest. Crops were picked for four breaks (4 wk) or more, depending on the experiment. When the harvest was complete, data were compiled into per break and total performance. These data were subjected to analysis of variance with means separated using Waller-Duncan standard t-test procedure available in SAS statistical software. In an effort to help interpret the response of different treatments (casing materials) in different experiments, results are presented as a percentage response compared to peat moss for each experiment.

2.4 *Mushroom Test Demonstration Facility (MTDF)*

The MTDF is a prototype of a commercial, multiple zone tray farm equipped with computer-controlled environmental equipment. Compost ingredients and processing are similar to what was described for the MRC, except supplementation which was done at casing with ground soybeans. Trays of compost and casing were processed and handled on a modified *Hauser* tray line.

Table 1. Analysis of materials sampled when being applied as mushroom casing.

Trait	Peat[c]	C'gro[d]	Pt wl[e]	Orfa[f]	RPC+[g]	FlyAsh[h]
pH (solution)	7.6	7.9	7.4	7.3	7.5	7.7
pH (buffer)	7.0	7.0	7.0	ND	ND	7.0
K (meq. $100g^{-1}$)	0.12	0.06	0.15	4.1	0.81	0.23
Mg (meq. $100g^{-1}$)	1.2	0.9	4.4	1.4	1.1	6.4
Ca (meq. $100g^{-1}$)	24.5	19.2	9.0	9.0	9.5	47.5
Cation Ex. Cap.	25.8	20.3	13.6	ND	11.5	54.1
K (% Satur.)	0.4	0.3	1.1	ND	0.81	0.4
Mg (% Satur.)	4.7	4.8	32.9	ND	1.1	11.9
Ca (% Satur.)	94.7	94.8	65.9	ND	9.5	87.6
Soluble salts[a]	25	19	ND	ND	81	34
NO_3-N(ppm)	60	57	ND	ND	ND	ND
% H_2O Hold	587	359	585	ND	420	ND
% Org. Matter	53.6	ND	29.1	88.8	80.2	ND
% Ash	46.4	ND	70.9	11.2	19.8	ND
% N	0.16	ND	ND	0.34	0.12	0.14
Cd (mg kg-1)[b]	<0.3	ND	ND	2.0	<0.2	0.5
Cr (mg kg-1)[b]	1.3	ND	ND	14.7	4.1	18.5
Cu (mg kg-1)[b]	1.9	ND	ND	48.6	20.9	2.5
Pb (mg kg-1)[b]	3.9	ND	ND	72.3	1.0	20.0
Hg (mg kg-1)[b]	0.06	ND	ND	0.6	0.05	ND
Ni (mg kg-1)[b]	1.3	ND	ND	7.8	2.0	20.0
Zn (mg kg-1)[b]	6.4	ND	ND	222	39.4	90.0

[a] Soluble salts, mmhos cm^{-1} x 100, >180 excessive, >80 high; [b] mg kg^{-1} = ppm; [c] Sphagnum peat moss mixed with ground limestone; [d] Capogro, U.S. Gypsum Co., Inc., mixed with limed-peat moss @ 25% to 60% (v/v); [e] Peatwool, Tetra, Inc., Elizabeth, CO, mixed with limed-peat at 40% (v/v); [f] Orfa Fibre, Orfa, Inc., Cherry Hill, NJ, mixed with limed-peat at 25 to 50% dry wt; [g] Phoenix Paper Products, Inc., Lostant, IL., used as received; [h] FlyAsh, randomly sourced, mixed with limed-peat at 25% dry weight.

Casing was mixed and watered, placed into a special bin, steam pasteurized with aerated steam at 60C for 2 hr. Casing from the bin was dumped into a soil mixer when cool, watered and mixed with Cac, and the Cac'd casing was layered onto tray surfaces to provide ca. 4 cm depth of casing on each tray. Trays were moved to a case-hold/pinning room and were placed into a growing room after pins had been set and 1st break irrigation had begun. Crops were picked for 4 to 6 wks, with #1 grade mushrooms weighed after each day's harvest. Picking data were collated and summarized at the end of each break and when picking ceased.

Experiments were designed to provide for time-related repetitions of a single variable. Consistency in production from crop to crop provided reliability for data analysis.

3 RESULTS AND DISCUSSION

3.1 *Suitability of casing materials*

It is significant that the five products supported mushroom crops equivalent to those grown on sphagnum peat moss. The common characteristics of the materials were: 1) their ability to hold and release generous amounts of water, related to their fibrous nature; 2) reasonable levels of soluble salts, Table 1.

Peat moss is difficult to wet and it seems unable to release the water it holds to mushroom mycelium. Casing materials that originated from the recycling stream or from manufactured molten rock were easy to moisten and appeared able to release all of the water they held to the mushroom mycelium. Water is bound to organic particles by adsorption or electrical charges, but these forces were not as strong in the non-peat moss casing materials. Although peat moss has the highest water holding capacity, it may have a limited ability to supply water to growing mushrooms.

Levels of K, Mg and Ca seem acceptable since the performance of the casings was not deterred. Heavy metal content of mushrooms was not excessive with *Orfa* fiber or Fly Ash casing. Mushrooms from sphagnum peat moss and the two alternative casing materials had similar contents of heavy metals (P.J. Wuest, D.M. Beyer, unpublished). It is judicious to monitor chemical constituents in mushrooms as an on-going quality assurance technique, but it appears heavy metals do not accumulate in button mushrooms grown in commercial conditions.

Experimental results suggest sphagnum peat moss can be replaced or extended by one or more of the materials studied. Three products appear to support mushroom production as well as sphagnum peat moss, *Capogro, RPC+* and Fly Ash, Table 2. Mushroom casing must be managed appropriately to assure crop performance is maximized. Because each casing material requires different handling, it is necessary to repeat experiments and adjust irrigation and crop management practices. Experiments referred to in this paper were initially nurtured and managed in the best interest of sphagnum peat moss, resulting in less than ideal management for the alternative casing materials until crop management was modified to favor them. The time it took to learn good management practices allowed a range of performance to be measured. Range response values, Table 2, provide a guide to the potential loss or gain in mushroom production when a material is used with or as a substitute for sphagnum peat moss casing.

Others have reported on the success of casing materials other than sphagnum peat moss. Most recently, Noble and Gaze (1995) reported recycled rockwool, 50% (v/v), added to sphagnum peat moss resulted in production equal to peat moss alone. Paper products were first reported as peat moss substitutes by Yeo and Hayes (1978) who investigated a by-product paper sludge generated at a paper-making facility. Eicker and van Greuning (1989) reported on a different paper product, that supported mushrooms of higher quality and yields equal to those of peat moss. Dergham *et al.* (1991) reported similar findings, but with a different paper product. Morris and Wuest (1995) provided additional corroborative evidence on performance related to a pelletted paper product, and they provided specific data on increased income from mushrooms grown on *RPC+*. Labuschagne *et al.* (1995) reported on a fibrous natural product (shredded coconut husks), *Coir* fiber, that when mixed with indigenous peats of Africa, performed as well as other casing materials.

Table 2. Comparison of materials other than Sphagnum peat moss for mushroom casing.

	Capogro[c]	Peatwool[d]	OrfaFiber[e]	RPC+[f]	Fly Ash[g]
versus Sphagnum peat moss[a]	N.S.D.	N.S.D.	N.S.D.	N.S.D.	N.S.D.
Range of response[b]	-19% to+7%	-13% to+.01%	- 9% to +.01%	-12% to+5%	-11% to+2%

[a] Comparison of biological efficiencies of two casing materials from experiment where water management was not an impediment to performance, N.S.D. = no significant difference; [b] Range of response considers all experiments where the yield from peat and another casing material were compared by calculating upper and lower limits of biological efficiency, expressed as a percentage; [c] Capogro used at 40% to 60%(v/v) with peat moss; [e] Orfa Fiber was mixed with 50% peat moss (v/v) with 40% coarse fiber, 10% fine fiber; [f] RPC+ was not mixed with peat moss, it was used as received; [g] Fly ash mixed with limed-peat at 25% dry weight.

3.2 *Adoption of alternate casing by mushroom farmers*

Mushroom farming in Pennsylvania and the U.S. can be characterized as being efficient, consistent, not uniform and very productive. This means growers devise procedures and strategies that work at their farms. Since most farms are unique in construction, ventilation, site, latitude, climate and so forth, there are as many ways to grow mushrooms as there are mushroom farmers. A survey of crop management methods would reveal a minimum of 40 to 50 unique methods to grow mushroom crops. Sphagnum peat moss is handled as uniquely as all other cropping variables. Even Sphagnum peat moss has enough variation to cause six to eight peat moss companies to compete for sales to mushroom farmers. This variation in peat moss products reflects the desires of different mushroom growers. Some mushroom farmers prefer fine peat moss, others coarse peat moss, while others blend different size-grades of peat moss. Much of the peat moss originates in the Maritime Provinces of Canada, but some prefer to source their peat from western Canada. It is reasonably common for a single technology, method or product to be judged by some mushroom farmers as desirable, while others reject it because of its inadequacy.

Such a range of responses results in the necessity to provide guidelines to those who chose to adopt a new product or process. The guidelines serve as a starting place and each mushroom grower changes the guidelines to serve his/her purpose. Growers modify guidelines repeatedly until they are satisfied the product or technology is performing at peak efficiency at their farm. Pennsylvania and U.S. mushroom growers are eclectic, very individualized, educated and motivated, and there is always interest in a new product. The challenge to one trying to introduce a new product or technology to this group of farmers is significant, but it can be managed with long-term, individualized assistance.

This synopsis of mushroom farmer traits may partially explain the difficulty in having anything new adopted by this heterogeneous group of farmers. Sphagnum peat moss has been the casing of choice for 20 years in Pennsylvania. A new casing product must perform in a way that makes it attractive. Significantly higher yields always attract farmers. *Capogro* and *RPC+* have the potential to increase yield significantly. Data in Table 2 suggest these two products have a yield gain potential of between 5% and 7%, with a yield loss potential of up to 12% to 19%. It is likely some farmers will experience yield losses and yield gains as compared to sphagnum peat moss, as they modify crop management strategies for a new casing material.

Mushrooms from *RPC+* and *Capogro* are brighter in color, have extended shelf life, and, overall, appear to be better quality products than mushrooms produced on sphagnum peat moss. Mushrooms grown on *RPC+* tend to be larger which results in faster picking and, concurrently, lower picking costs. Are improved quality, lower picking costs and more income per unit area of production sufficient to attract the interest Pennsylvania mushroom farmers? In the case of *RPC+*, these improvements enhanced the gross and net income from each square meter (ft^2) of production surface, Morris and Wuest (1995).

3.3 *Business decisions regarding an alternative casing*

A deciding factor in adopting a new product are its costs, benefits and risks. Benefits and risks have been reviewed. The cost of a product reflects the unit price when purchased and the amount of material needed

to garner the benefits. *Capogro* shrinks in volume when it is wetted. To obtain a desired casing depth, more *Capogro* is needed (volume) than is expected with peat moss. A mixture of peat moss and *Capogro* does not cover as many m^2 (ft^2) of mushroom compost as peat moss alone, requiring more of the mix to case the same area to a desired depth. Between 50% and 70% more casing is needed to cover the same area at a desired depth. This aspect of *Capogro* may result in an increased cost for casing on a per square area basis. When net income per square area equals or exceeds that of sphagnum peat moss casing, a choice for an alternate casing makes business sense.

The unit cost of *RPC+* can be affected by the cost of its stock, the wholesale market for recycled newspaper, that fluctuates in price. In addition to a cyclic wholesale market for recycled newsprint, stock paper, *RPC+* must be applied to mushroom compost at 1.3 to 1.4 times the dry weight of sphagnum peat moss to obtain the yield results reported in this paper. Use of *RPC+* resulted in mushrooms of higher quality and the net income per unit area exceeded that of sphagnum peat moss, making the use of *RPC+* a sound business decision, Morris and Wuest, (1995). *Orfa Fiber* is not available because the processing facility is not operating at this time. Whether *Peatwool* is available is not known to the authors. Both *Capogro* and *RPC+* are available as of this writing.

4 CONCLUSIONS

It was proposed earlier that adoption of an alternative to sphagnum peat moss for mushroom casing is not only a matter of whether the alternative material has the ability to support bountiful crops. Research reported in this paper and research reported by others indicates a few products satisfy this criterion. Consistent performance, a reliable supply, competitive costs, ease of storage, transportation and handling are other factors that have little to do with science, but have a great deal to do with a farmer's decision to change casing materials. We will learn whether sphagnum peat moss retains its prominent position as the casing of choice in the years ahead, while scientists continue the search for more efficient, less costly mushroom casing.

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