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Brigitte Li-Shing-Tat

Pavel Jelen

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THE MICROSTRUCTURE AND REHYDRATION PROPERTIES OF THE PHOENIX OYSTER MUSHROOM  
(*PLEUROTUS SAJOR-CAJU*) DRIED BY THREE ALTERNATIVE PROCESSES

Brigitte Li-Shing-Tat and Pavel Jelen\*

Department of Food Science, University of Alberta  
Edmonton, Alberta, Canada, T6G 2P5

Abstract

The aim of this investigation was to observe the effects of three drying methods on the microstructure and rehydration properties of the Phoenix Oyster mushroom. Mushrooms were dried at 55°C by air-, freeze-, and vacuum-drying pilot plant processes. At the microstructural level, the hyphae of the air-dried samples were more flattened and collapsed than the vacuum- and freeze-dried samples. The basidia were distorted by all three treatments to a certain extent, but there seemed to be less damage on the gill surface of the vacuum-dried samples. Appearance, rehydration time and capacity were similar for freeze- and vacuum-dried mushrooms; air-dried mushrooms were shrunken and darker in colour, and their rehydration time and capacity were lower. Sensory evaluations indicated better flavour retention of the vacuum-dried product as compared to the air-dried material.

Introduction

Edible mushrooms can be processed by various methods including canning, drying and freezing. The effects of these processes on the mushroom macrostructure are well documented. However, few studies have been concerned with the microstructure of processed mushrooms. Jasinski *et al.*, (1984) observed the ultrastructural changes of blanched and canned mushrooms of *Agaricus bisporus*, while Keresztes *et al.*, (1985) studied the effect of ionizing radiation on the gill tissue of *Agaricus bisporus* and *Pleurotus ostreatus*.

Two methods of commercial importance for the drying of mushrooms are air drying and freeze drying (Cho *et al.*, 1982). Air drying is more commonly used for preserving many wild varieties of edible mushrooms and some cultivated species such as *Lentinus edodes* and *Volvariella volvacea*. The main advantage of dehydrated mushrooms is that they are light and thus can be packaged, stored and transported cheaply. Air-dried products are often of poor quality due to shrinkage, textural changes, browning and incomplete rehydratability (Van Arsdell, 1973). The time taken by the dried mushrooms to rehydrate depends on the species concerned. Air-dried Chanterelles, *Cantharellus cibarius*, take up to 8 hours while air-dried *Pleurotus ostreatus* take about forty minutes (Gormley and O'Riordain, 1976). In contrast, freeze-dried mushrooms rehydrate within a few minutes because of their porous, non-shrunken structure. They also have a good colour and flavour (Fang *et al.*, 1971). However, there are problems with freeze drying of mushrooms resulting from the damage incurred by the freezing stage of the process (King, 1975). Oddson and Jelen (1981) observed that rehydrated freeze-dried *Pleurotus florida* were limp, probably due more to the inability of the delicate structure of the mushrooms to withstand the freezing process than the drying itself.

During freezing, mechanical injury can result from the growth of ice crystals which occupy a larger volume than water. If the ice

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Direct inquiries to P. Jelen  
Telephone number: 403 432 2480

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crystals are large enough, physical rupture can occur (KuprianoFF, 1962). Slow freezing favours the formation of large extracellular ice crystals while rapid freezing promotes the formation of small intracellular ice crystals which are less likely to cause structural damage (Fennema, 1975). Bello *et al.*, (1984), however, showed that even with rapid freezing, damage to the nuclei and mitochondria of skeletal fish muscle could occur.

Smaller ice crystals may not be necessarily desirable for the freeze-drying process, since they result in pores of smaller diameter which offer a greater resistance to heat and mass transfer during drying (Ciobanu *et al.*, 1976). Also, rapid freezing results in a greater loss of volatile components. Bartholomai *et al.* (1975) reported a significant reduction in the retention of a natural volatile component in liquid mushroom extract frozen rapidly in liquid nitrogen compared to the extract frozen slowly in still air at -40°C. Flink (1975) suggested that slow freezing allows a greater incorporation of volatiles into the solute phase and favours the formation of microregion structures in which the volatiles are entrapped. Thus rapid freezing may minimize structural damage but it does not maximize volatiles retention.

Since the freezing step appears to be the main cause of quality impairment of freeze-dried mushrooms, it was decided to investigate the effects of bypassing that stage and only subjecting fresh mushrooms to the drying conditions usually used for freeze drying, i.e., heating under high vacuum. The aim of this study was to compare three drying methods (i.e., air-drying, freeze-drying, and high vacuum-drying) for their effects on the microstructure and rehydration properties of the Phoenix Oyster mushroom, *Pleurotus sajor-caju*. The mushrooms were also evaluated for sensory characteristics such as texture, flavour and overall acceptability.

#### Materials and Methods

##### Samples

Fresh *Pleurotus sajor-caju* (Strain P60, Hauser Champignonkulturen Ag, Switzerland) mushrooms were obtained from Mountain Mushrooms Research Farm (Airdrie, Alberta). Fruit bodies of 7-10 cm diameter were selected. Only the caps were used.

##### Drying Treatments

Gormley and O'Riordain (1976) recommended a temperature of 51-65°C for air-drying of *Pleurotus ostreatus*. Bartholomai (1974) reported obtaining dried mushrooms of satisfactory sensory quality from mushrooms dried by a combination of freeze-drying (contact freezing at -40°C; heating plate at 60°C) and air-drying at 80°C. A temperature of 55°C was used in our work for all three drying methods as a compromise and uniform treatment.

Nine hundred grams of whole mushroom caps on a perforated tray were dried to a moisture content of 7-8 % by the three methods investigated. Each treatment was replicated

three times using three different batches of mushrooms. The methods used were: (i) Air drying in a forced convection oven (model LDBL-69, Despatch Industries Inc. Minneapolis, MN). The drying time was approximately 10 h. (ii) Freeze drying, for approximately 20 h. Mushrooms were previously frozen in a walk-in freezer (air-blast) at -30°C. They were next dried in an RePP freeze drier (Virtis Co. Inc., Gardiner, NY); the shelf temperature was maintained at 55°C and the condenser temperature at -60°C; the vacuum was less than 1 mm Hg. (iii) High-vacuum drying, using the equipment and drying conditions as in (ii), but omitting the freezing step.

##### Temperature Changes in Mushrooms

The temperature changes in a mushroom cap of 10 cm diameter were monitored by several thermocouples inserted at various locations during vacuum-drying.

##### Scanning Electron Microscopy (SEM)

Samples were prepared according to the method described by Nickerson *et al.* (1974) for fungal spores. Small pieces (5 mm<sup>2</sup>) of gill tissue and inner tissue of a cap were exposed to osmium tetroxide vapour overnight and air dried at room temperature. The dried samples were then sputter coated with gold (Nanotech, Sempreg 2), and examined with the scanning electron microscope (Cambridge stereoscan model S250, Cambridge Industries, England) at 20 kv.

##### Moisture Content of Mushrooms

Approximately 3 g samples of dried mushrooms, crushed into small pieces, were dried at 105°C for 3 days. Moisture loss was then calculated. Determinations were carried out in duplicate.

##### Rehydration Time

About 2 g of dried mushrooms were soaked in 500 mL of water at 20°C. After a specific time interval, the mushrooms were removed and excess water gently blotted out by paper towel. The samples were weighed and then placed back into water. The time interval used for repeated determinations of air-dried mushrooms was 10 minutes while for the freeze-dried and high vacuum dried mushrooms, it was 30 seconds. Readings were taken until there was no further change in weight, at which time the mushrooms were considered to have reached full rehydration capacity. Determinations were made in triplicate.

##### Rehydration Capacity

Rehydration capacity was calculated as the maximum amount of water absorbed (g) per g of dry material as determined at the end of the rehydration time experiment. Determinations were made in triplicate.

##### Sensory Evaluation

Mushrooms were rehydrated and cooked in butter for two to three minutes. They were evaluated for texture, flavour and overall acceptability by a group of twenty-six panelists on a hedonic scale (Larmond, 1977) of 1 (dislike extremely) to 9 (like extremely). Results were analyzed by two way Analysis of Variance (ANOVA). Differences between means were tested by the Tukey's test.

### Results and Discussion

The freeze-dried and vacuum-dried mushrooms were similar in several aspects. They both exhibited good colour, little or no shrinkage (Fig. 1), and rehydrated within two minutes to a similar rehydration capacity (Table 1). In contrast, the air-dried mushrooms were darkened and shrunken; they took forty minutes to rehydrate and their rehydration capacity was lower.

At the microstructural level, the basidia of all three samples (Fig. 2) were distorted to a certain extent but there seemed to be less damage on the gill surface of the vacuum-dried samples. When rehydrated, the gill surface of the air-dried sample was more wrinkled than that of the freeze-dried product while the surface of the vacuum-dried sample was fairly smooth (Fig. 3). The hyphae of the air-dried samples were more flattened and collapsed than those of the freeze-dried and vacuum-dried (Fig. 4) samples. The rehydrated hyphae of the air-dried samples were more folded while those of the freeze-dried and vacuum-dried products were fairly smooth (Fig. 5).

According to Van Arsdell (1973), during drying the solid structural elements of the plant tissue are pulled closer together under the influence of surface tension as water evaporates from the wet surface. This effect eventually spreads to the deeper layers while water migrates to the surface where it is evaporated. Additional removal of water at the surface leads to further deformation as the structural elements are crumpled or folded to occupy a shrinking volume. Thus, the air-dried mushrooms were shrunken, the hyphae flattened and the basidia collapsed.

During freeze-drying, the original dimensions of the product are maintained first by freezing. The ice is then sublimed, usually under a high vacuum. Since there is no aqueous phase, there is no migration of water to the surface but instead a receding interface of frozen and dry layer. The effects of shrinkage and concentration of water soluble components due to the mobility of the aqueous phase are thereby prevented (Karel, 1975), and the resulting product is not shrunken but porous. At the microstructural level this was observed as hyphae which had retained to some degree their tubular structure (Fig. 4B). The basidia, however, were more damaged and some showed perforations in their wall (Fig. 2B). In this experiment, the mushrooms were frozen by air-blast freezing at  $-30^{\circ}\text{C}$ . At this rate of freezing, there could have been the formation of ice crystals large enough to cause structural damage. To assess the extent of the damage, further observations at the ultrastructural level by electron transmission microscopy need to be carried out.

Temperature probes placed in the mushroom cap (Fig. 6) monitored the temperature changes occurring during vacuum-drying (Fig. 7). There was an initial rise in the temperature of the tissue but after five minutes, the temperature dropped steadily reaching its lowest point

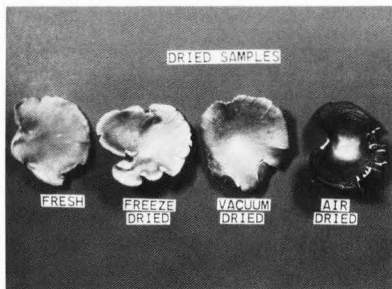


Fig. 1. Fresh and dried samples of *Pleurotus sajor caju* mushrooms.

Table 1. Moisture Content and Rehydration Characteristics of Dried Mushrooms (at  $20^{\circ}\text{C}$ ).

Dried Sample	Moisture* (%)	Rehydration Time (minutes)	Rehydration Capacity** (g H <sub>2</sub> O/g mushrooms)
Air	7.4 ( $\pm 0.1$ )	40	6.39 ( $\pm 0.06$ )
Freeze	7.6 ( $\pm 0.3$ )	1.5	7.21 ( $\pm 0.05$ )
Vacuum	7.6 ( $\pm 0.1$ )	2	7.16 ( $\pm 0.07$ )

\* Mean  $\pm$  standard error (n=6)  
 \*\* Mean  $\pm$  standard error (n=9)

after fifteen minutes when the pressure within the dryer reached one Torr. As the pressure within the dryer was being reduced, water evaporated rapidly from the mushroom. Heat was lost from the tissue as latent heat of vaporisation but at the same time there was a heat gain from the heating plate and the surroundings. While the other parts of the mushroom cap remained above  $0^{\circ}\text{C}$  at the time intervals recorded, the temperature dropped to  $-8.2^{\circ}\text{C}$  in the centre of the cap. Whether that area became supercooled or frozen has to be investigated further. The porosity of the vacuum-dried mushroom indicates the possibility of a similar mode of mass transfer in the tissue as that occurring during freeze-drying. Instead of a migration of water which would pull the tissues together, there could have been a receding interface of moist and dry layer which resulted in a porous structure, as shown for the vacuum-dried hyphae (Figs. 4B and 4C). The gill surface of the vacuum-dried sample, on the other hand was not as damaged as the freeze-dried sample (Figs. 2B and 2C). This may be due to the omission of the freezing process. The kinetics of heat and mass

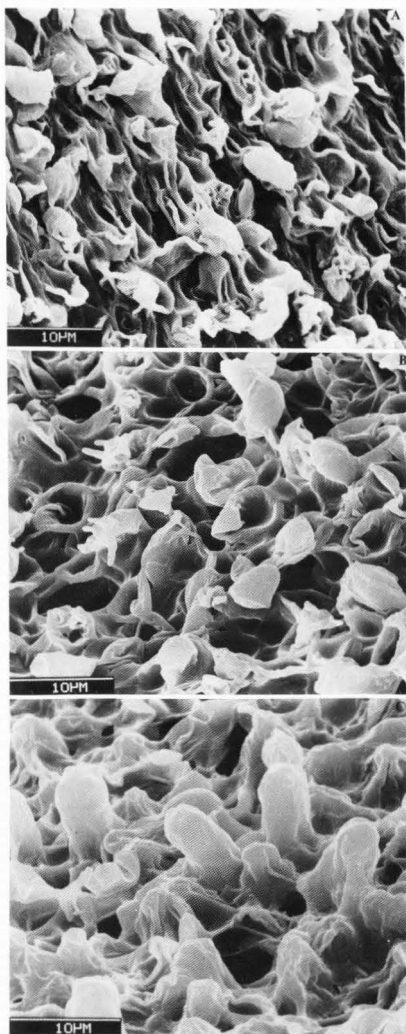


Fig. 2. Gill surface of *P. sajor-caju* mushrooms. A - Air dried. B - Freeze dried. C - Vacuum dried.

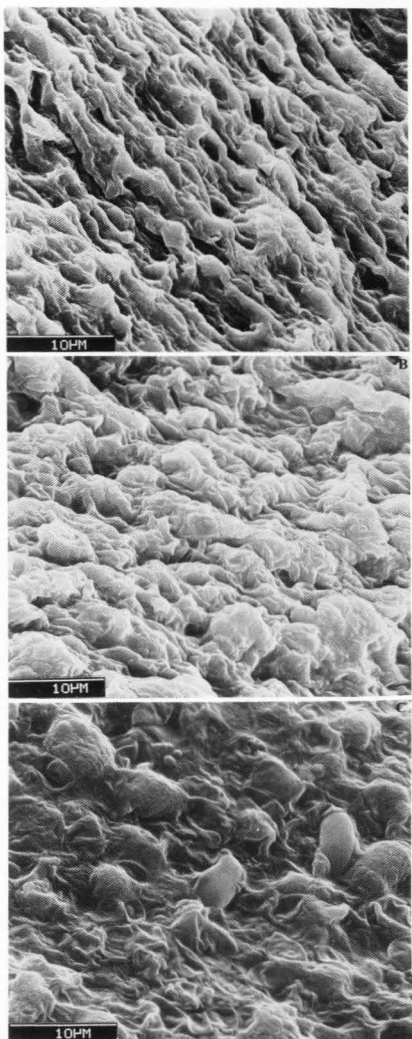


Fig. 3. Gill surface of rehydrated *P. sajor-caju* mushrooms. A - Air dried. B - Freeze dried. C - Vacuum dried.

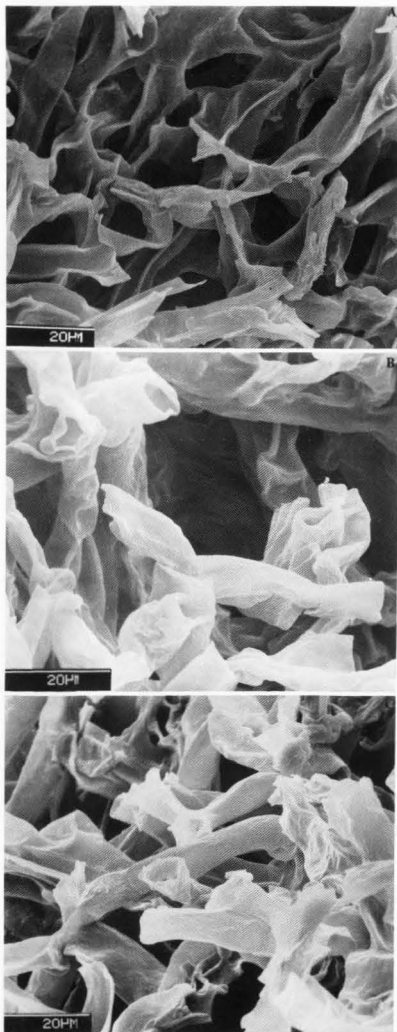


Fig. 4. Hyphae from *P. sajor-caju* mushroom caps. A - Air dried. B - Freeze dried. C - Vacuum dried.

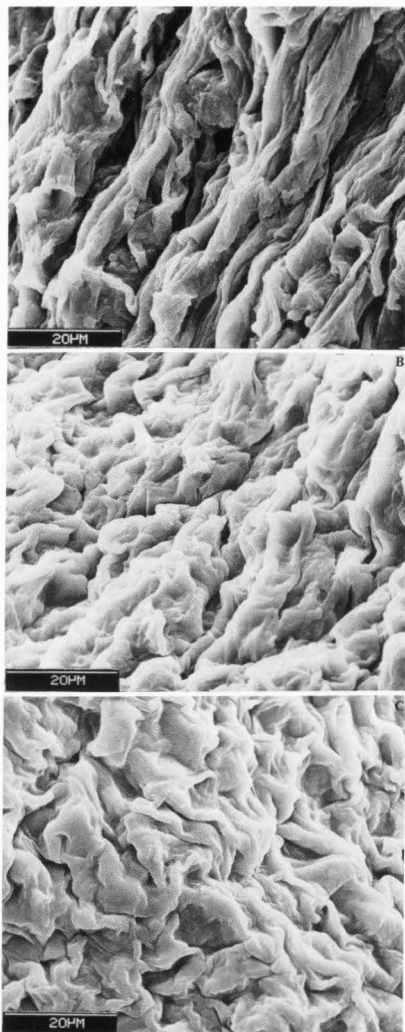


Fig. 5. Hyphae from rehydrated *P. sajor-caju* mushroom caps. A - Air dried. B - Freeze dried. C - Vacuum dried.

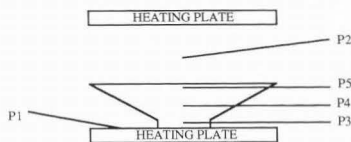


Fig. 6. Schematic diagram showing locations of temperature probes in mushroom cap during vacuum drying.

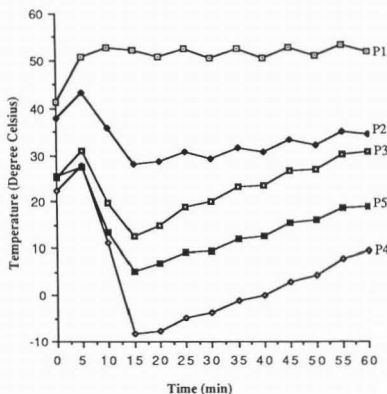


Fig. 7. Temperature changes in mushroom cap during vacuum drying.

Table 2. Summary of results (mean scores, n=26) from the sensory evaluation of fresh and dried caps *Pleurotus sajor-caju*.

	Fresh	Vacuum-Dried	Freeze-Dried	Air-Dried
Texture	<u>6.85</u>	5.13	5.33	5.12
Flavour	<u>7.06</u>	6.10	5.81	5.33
Overall Acceptability	<u>6.85</u>	6.0	5.75	5.35

Mean scores underscored by the same line are not significantly different at 5% level (Tukey's test).

transfer in the mushroom tissue would have to be investigated further before an explanation can be given for the similar porous structure of the freeze-dried and vacuum-dried samples.

Panelists used in the sensory test indicated no significant difference between freeze-dried and vacuum-dried mushrooms with respect to texture, flavour and overall acceptability (Table 2). However, flavour and acceptability of the vacuum-dried mushrooms were significantly better than that of the air-dried products, while the freeze-dried mushrooms were not significantly different from the air-dried mushrooms. This indicated that flavour might be better preserved in the vacuum-dried mushrooms than in the freeze-dried products but this was not significant enough to be detected by the panelists. The freeze-dried mushrooms could have lost more of the flavour components by leakage through the damaged cell walls when they were being rehydrated prior to cooking. In all tests, however, fresh mushrooms scored significantly higher than any of the three dried products.

#### Conclusion

High vacuum drying is a method of potential importance for drying mushrooms. Vacuum-dried Phoenix Oyster mushrooms had similar features to those of the freeze-dried mushrooms such as good colour, non-shrunken structure and rapid rehydration rate to a high rehydration capacity. The absence of a freezing stage would avoid the undesirable characteristics associated with freezing and would also reduce the processing cost for obtaining quality dried mushrooms. This method could be applied to other mushrooms such as the Chanterelles, (*Cantharellus cibarius*) which give poor quality air-dried products while freeze-dried products are too expensive. A preliminary study on the Chanterelles (Li-Shing-Tat and Jelen, manuscript in preparation) indicated that the freeze-dried and vacuum-dried mushrooms were similar in appearance. The high vacuum drying method merits further investigation, especially for the edible mushrooms commanding premium prices.

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#### Discussion with Reviewers

D.L. Rinker Substrate, culture and environment influence the quality of the fresh

product. Would the result of the experiment be any different under different substrate, culture and environmental parameters? Also, there are many species of *Pleurotus* cultivated commercially. How would your technique or results vary with the different species?

Authors: Mushrooms subjected to the three drying treatments all came from the same batch. The relative difference between the dried products would probably be similar for mushrooms cultivated under a different set of conditions and for mushrooms of different *Pleurotus* species.

D.L. Rinker: Why were caps only used? *Pleurotus sajor-caju* is a cultivar of choice by some for the edibility of the stems. There is considerable weight loss (dollar loss to the producer) if the stipes are trimmed short.

Authors: Air-dried stems are tougher in texture than the caps. Also, because of the differences in structure between the caps and the stems, they would dry at different rates. In this experiment, it was decided to concentrate on the caps. Oddson and Jelen (1981) indicated that freeze-drying was damaging particularly to the structure of the caps.

E. Kovacs: Were the ultrastructural changes observed correlating with texture measured by an objective method (Instron) or only by sensory evaluation?

Authors: The textural characteristics of the rehydrated uncooked mushrooms were measured by the Ottawa Texture Measuring System of Voisey (1971). J. Inst. Can. Technol. Aliment. 4 (3) 91-103). There was no significant difference between the vacuum-dried and freeze-dried products (Table 3).

Table 3.

Force (kg) required to shear through rehydrated *Pleurotus sajor-caju* mushrooms (using an Ottawa Texture Measuring System apparatus).

Sample	Force (kg)/25g
Air-dried mushrooms	73.54 ( $\pm 1.43$ )*
Vacuum-dried mushrooms	51.55 ( $\pm 1.27$ )
Freeze-dried mushrooms	50.11 ( $\pm 5.64$ )

Mean values  $\pm$  S.E. (n=9)

\*Significantly different at 5% level

E. Kovacs: Do you plan to investigate other mushrooms, for example wild mushrooms, which are very rich in flavour components? *Pleurotus* species are generally poor in



flavour components; why did you choose *Pleurotus sajor-caju*?

Authors: *Pleurotus sajor-caju* was chosen in this study because of its rising importance in the exotic mushroom industry in Canada, and the current industrial interest in finding suitable processing technologies for the excess production. However, the final objective was to find a method of drying that could be applied to high value mushrooms such as the Chanterelle. Preliminary tests on *Cantherellus cibarius* indicate that the vacuum-drying method gave a similar product to that obtained by freeze-drying.

E. Kovacs: Were the dried samples investigated right after drying or after storage? If the dried product was stored, please clarify the storage conditions.

Authors: After drying, the products were stored in moisture-proof bags at room temperature. Samples for investigation were prepared within a week after drying treatments.

E. Kovacs: It would be interesting to know whether there are any differences in brittleness of the dried, freeze-dried and vacuum-dried products. It is important from a consumer's point of view.

Authors: The differences in brittleness between the three dried products were not tested. The vacuum-dried and freeze-dried products were both fragile and would require protective packaging.

P.T. Atkey: Have the authors considered any other methods of preparing specimens for SEM which might be less damaging to the tissue?

Authors: Specimens were dried samples which had already been damaged by the drying treatments. It is possible that the preparation technique employed here will cause further damage to the tissue but it is expected that all samples will suffer the same degree of damage and that the relative difference between the samples can still be assessed. Another method that could be used for the specimen preparation is Cryo-SEM.

P.T. Atkey: Have the authors looked at fresh tissue as control test for the techniques they used for specimen preparation for the SEM?

Authors: Fresh tissue was not included as control since the aim was to compare dried samples. A technique that preserves the structures of the fresh tissue may not be necessarily suitable for the dried samples. In retrospect, fresh tissue as control might have been useful to assess the structure of the rehydrated samples.

P.T. Atkey: An increasingly important method of short-term mushroom preservation is vacuum cooling. Have the authors examined the effects this may have on *Pleurotus* tissue?

Authors: No, this was not investigated.