CHAPTER 19

SELECTED CULTURAL AND HARVEST PRACTICES TO IMPROVE QUALITY AND SHELF LIFE OF *AGARICUS* MUSHROOMS

R.B. Beelman, M.B. Miklus, J.-L. Mau, S.O. Ajlouni and S.S. Simons

Department of Food Science, The Pennsylvania State University, University Park, Pennsylvania, USA.

1. INTRODUCTION

Cultivated mushrooms, especially the commonly grown strains of *Agaricus bisporus* are currently grown under intense conditions which can often result in compromised quality. Also, they are highly perishable and tend to rapidly lose the quality attributes that make them appealing to consumers, thereby reducing their value and/or market demand. Most consumers appear to favor tight buttons, light or white in color with smooth, unspotted surface appearance and a crisp, tender texture. Unfortunately, mushrooms may be off-white in color with scaly surface at harvest. At harvest, mushrooms may rapidly begin to darken, the caps open and expose the darkening gills as spores develop, the stems lengthen, and all of the tissues toughen and become chewy. These changes occur as a result of normal senescence phenomena and/or microbial activity. This paper will focus on research conducted at Penn State University related to identifying selected cultural and harvesting practices that can improve quality and shelf life.

2. TREATMENT OF IRRIGATION WATER WITH CALCIUM CHLORIDE

Extensive experimentation over the past 7 years has demonstrated that appropriate addition of calcium chloride to irrigation water reduces bacterial blotch, improves initial quality and postharvest shelf life without reducing crop yield (Beelman *et al.*, 1987; Barden *et al.*, 1990; Bartley *et al.*, 1991; Solomon *et al.*, 1991; Beelman *et al.*, 1992; Mau *et al.*, 1993a). Optimum results to date were achieved by addition of 0.3 per cent $CaCl_2$ (Dow Flake, Process R Grade; Dow Chemical Co, Midland, MI) to all water applied to the casing layer after pinset through the end of the crop.

Two recent crops were grown under semi-commercial scale conditions at the Mushroom Test Demonstration Facility (MTDF) on our campus. One crop (MTDF #1907 was treated with 0.3% calcium chloride and the other (MTDF #1906) served as an untreated (control) crop. The harvested

mushrooms were weighed to determine yield. The quality of mushrooms was determined by evaluating color using a Minolta Chromameter CR200. Color and maturity index (rate of cap opening) were determined during postharvest storage in PVC-overwrapped packages using methods employed routinely in our laboratory (Ajlouni, 1991).

The effects of calcium chloride added to irrigation water on yield and initial color of mushrooms at harvest are presented in Figure 1. The effect on postharvest shelf life as evidenced by postharvest browning is presented in Figure 2. Yield curves (Fig. 1A) illustrate that calcium chloride treatment gave a more even yield especially in the first and second flush. However, calcium chloride did not significantly reduce overall yield. Yields were 24.4 vs. 25.7 Kg/m^2, and biological efficiencies were 87.0% vs. 86.4% for $CaCl_2$ treatment and control, respectively. The data in Figure 1B clearly demonstrate that $CaCl_2$ added to irrigation water improved the colour (higher L value indicates whiter) of mushrooms from harvest throughout the crop cycle (Fig. 1B) despite the general decline in whiteness that occurred in later flushes. Also, mushrooms grown with added calcium chloride showed a reduced rate of postharvest browning compared to non-treated mushrooms (Fig. 2). Since calcium chloride is an inexpensive, food grade chemical commonly used to improve quality of fruits and vegetables, it appears that this technique has considerable potential to improve quality of fresh market mushrooms that can be easily employed by growers without any need for regulatory approval.

3. INFLUENCE OF MATURITY AT HARVEST

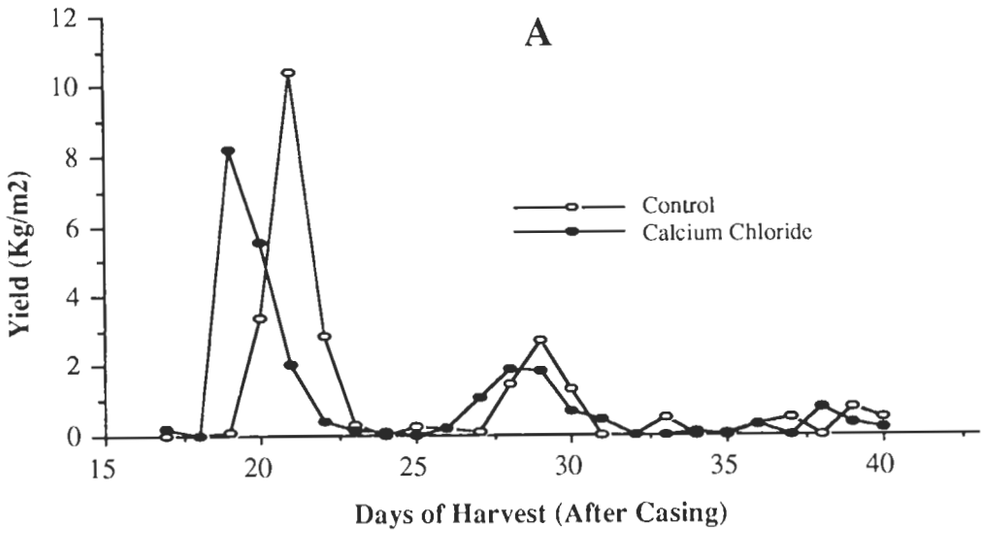
An experiment involving two crops using the same off-white hybrid spawn (Amycel U-1 #20) grown at the MTDF (Crops #1711 and #1715) employed the same cultural conditions except harvesting. Crop (#1715) was harvested normally (veils intact but slightly stretched) while the other (#1711) was harvested at a more immature stage (veils intact and tight). With crop #1711, pickers were instructed to harvest immature mushrooms by selecting those they would normally wait to pick the following day.

Surprisingly, harvesting more immature mushrooms resulted in slightly higher yield (33.4 vs. 30.0 kg/m^2 in five flushes) than the crop harvested normally (Fig. 3). Mushrooms harvested at a more immature state had better shelf life as evidenced by both a slower rate of browning (Fig. 4A) and reduced rate of cap opening (Fig. 4B).

These results indicate that harvesting mushrooms at an earlier stage of maturity can improve quality and shelf life without sacrificing yield. This could be an easy and inexpensive way for growers to improve the quality of their product. However, influence on mushroom size was not determined which should be done before this practice can be fully assessed for its potential. Also, this kind of experiment needs to be repeated to determine the consistency of the results that can be realized.

4. INFLUENCE OF STIPE TRIMMING AT HARVEST

Stipe trimming is the process of cutting off a portion of the lower stipe and the attached mycelium and casing material at harvest. Some mushroom growers instruct pickers to leave as much lower stipe as possible on the fruiting bodies (up to about 35mm) in order to maximize yield and consequent economic return. However, one noticeable feature of harvested mushrooms during storage is the elongation of the stipe; hence, mushrooms with short stipes result in proportionally less



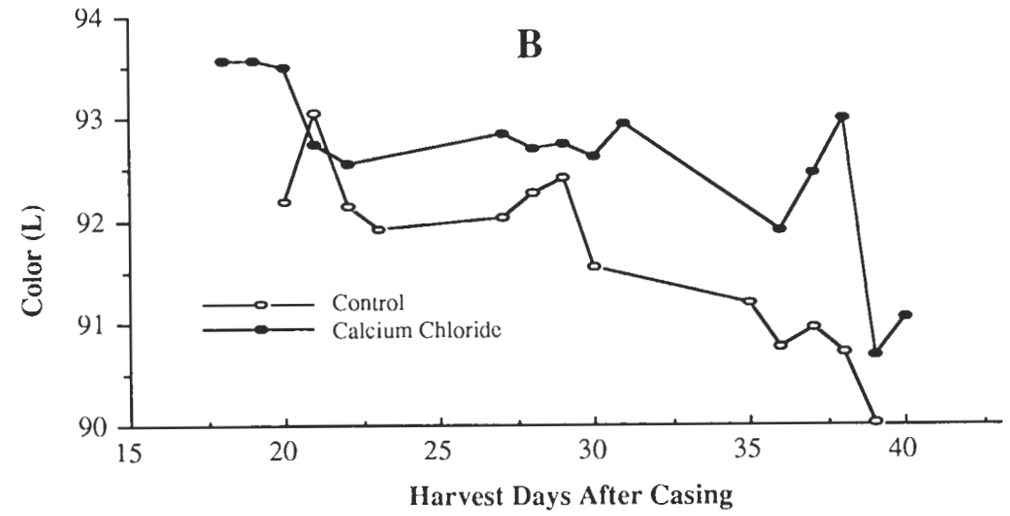


FIGURE 1. Influence of 0.3% calcium chloride added to irrigation water on (A) yield and (B) initial color (L value) of off-white hybrid mushrooms grown at the MTDF.

stipe after storage when compared to mushrooms with initial long stipes. Therefore, some growers trim stipes closer to the cap to minimize change in appearance after storage.

Recently, experiments in our laboratory have demonstrated that trimming stipes closer to the cap at harvest can also improve postharvest shelf life (Ajlouni *et al.*, 1993). They indicated that trimming the stipe of mushrooms, from 35mm to 5mm from the cap immediately after harvest resulted in improved shelf life as indicated by reduced browning and slower cap opening. This effect was evident after 3 days storage at 12°C and became more pronounced after 6 days. Trimming the stipes had no significant effect on postharvest respiration rate or bacterial growth. Thus, the shelf life

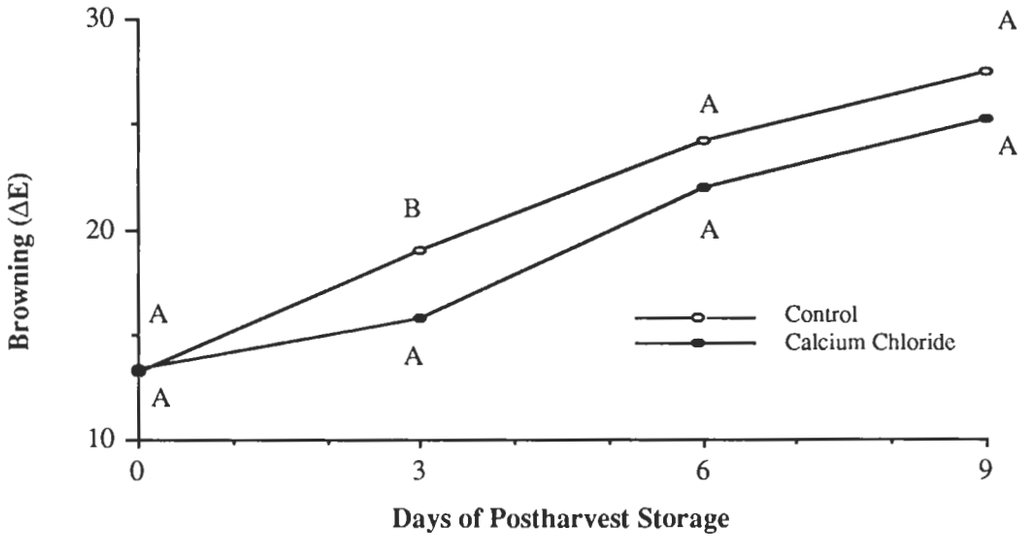


FIGURE 2. Influence of 0.3% calcium chloride added to irrigation water on postharvest browning (increase in ΔE) of mushrooms stored at 13°C in PVC-overwrapped packages. Data are means of results of flushes 1, 2 and 3. Means on the same day with the same letter are not significantly different at p=0.05.

improvement was thought to be due to other factors.

A possible explanation for these observations was related to mannitol translocation within tissues. The movement of dry matter from the lower stipe to the cap reportedly occurs even after harvest, and is apparently associated with mushroom postharvest development (Ajlouni, 1991). He also reported the lower stipe to be high in mannitol content (28% of the dry weight) as compared to

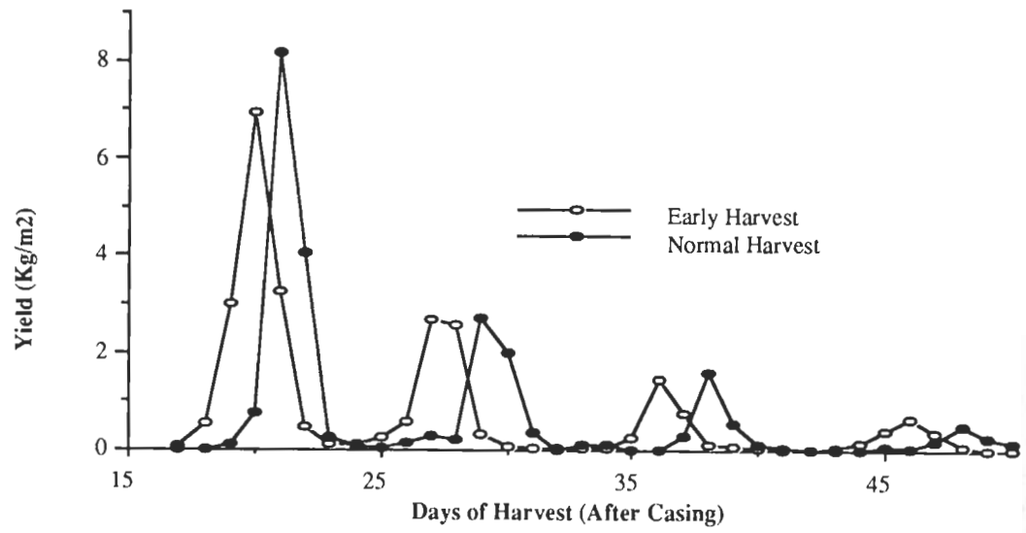


FIGURE 3. Influence of maturity at harvest on yield of mushrooms.

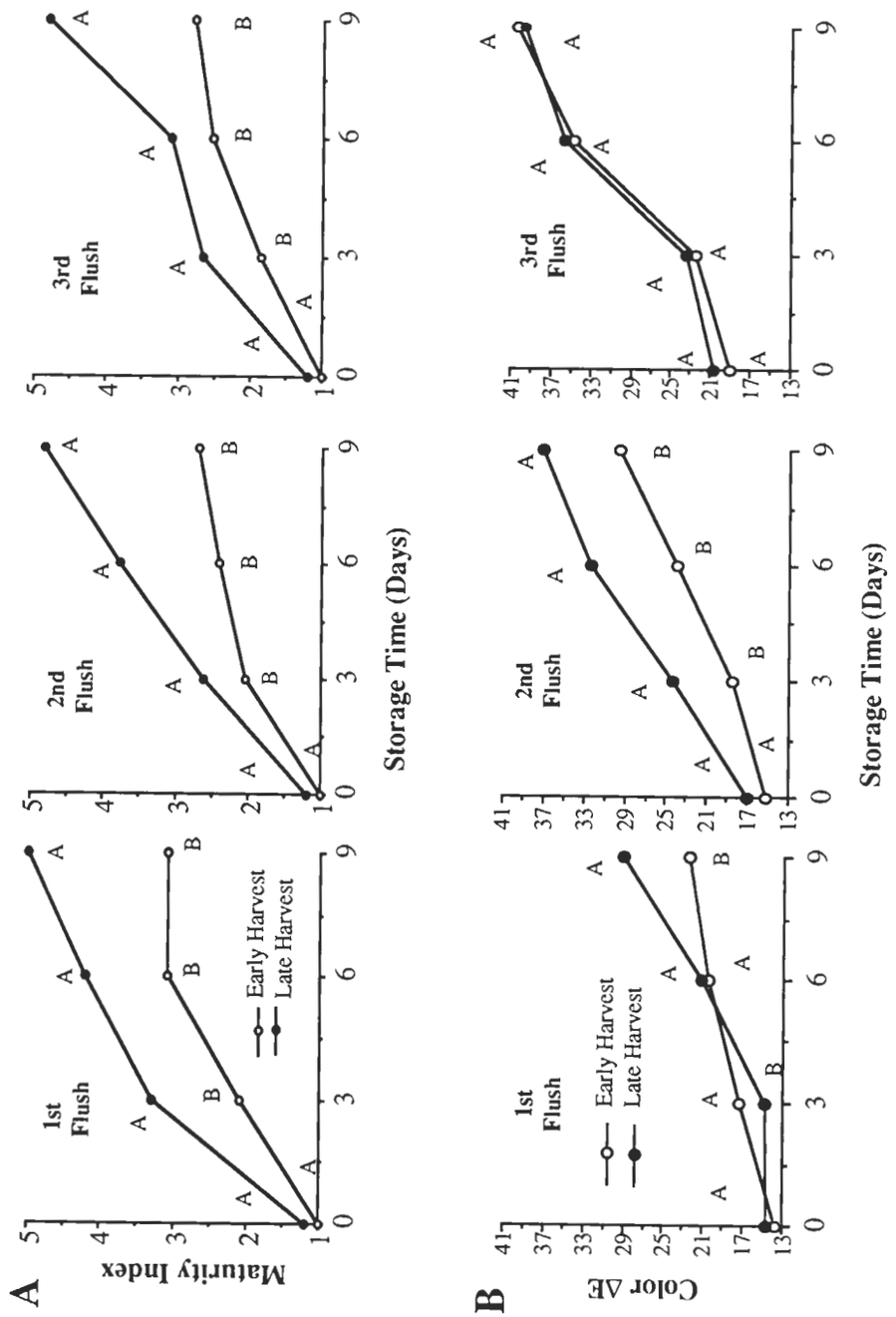


FIGURE 4. Influence of maturity at harvest on postharvest shelf life as indicated by (A) cap development (increase in maturity index) and (B) browning rate (increase in ΔE) in storage at 13°C. Means followed by the same letter on the same day are not significantly different at p=0.05.

the gills (10%) and the upper stipe (19%), and demonstrated apparent translocation of mannitol from the lower to the upper stipes during postharvest storage. Because the process of upper stipe cell elongation is involved in cap opening, normal maturation would be slowed if substrate for elongation were not available. Translocation of mannitol from the lower to the upper stipes of mushrooms could possibly create high osmotic pressure in the upper stipe and force the movement of water in the same direction. The continuous withdrawal of water into the upper stipe of mushrooms with long (untrimmed) stipes could stimulate the process of cell elongation and growth of the upper stipe that could, in turn, force the breakage of the veil and the opening of the cap.

In recent experiments conducted in our laboratory, Mau *et al.* (1992) demonstrated that 10-oxo-trans-8-decenoic acid (ODA) isolated from *Agaricus* mushrooms stimulated mycelial growth and stipe elongation at hormonal concentrations. This compound is produced concurrently with 1-octen-3-ol, the major mushroom aroma compound, by two enzyme catalyzed reactions when tissues of fruiting bodies or filaments of mycelium are disrupted. In one experiment conducted with separated stipes on agar plates (Mau *et al.*, 1992), isolated and purified ODA stimulated elongation of separated upper stipe tissue at concentrations as low as 10^{-8}M. However, the response occurred only when lower stipe tissue was left intact with the upper stipes. It was concluded that with the presence of the lower stipe tissue with the large pool of mannitol and water contained therein, the upper stipe tissue could respond to the stimulatory effect of ODA produced *in situ* or translocated from the gill tissue as could be the case in whole intact mushrooms.

This assumption was tested in a subsequent experiment. Mushrooms (Alpha Omega white hybrid #20-22) were harvested from the first flush at the MTDF by four different methods as follows:

1. SS (short stipe)-stipes were trimmed to 5mm immediately at harvest.
2. LS (long stipe)-stipes were trimmed to 30-35mm immediately after harvest.
3. SS2 (short stipe cut twice)-stipes were trimmed as LS at harvest and then trimmed again like SS about 3 hours later before packaging.
4. Whole-mushrooms were pulled from casing and were not trimmed but packaged with some mycelium and casing material attached.

Results of this experiment demonstrated that whole mushrooms did indeed have the most rapid rate of cap development in postharvest storage (Fig. 5A). It was also apparent that long stipes (LS) contributed to a faster rate of cap opening compared to mushrooms with stipes trimmed short (SS). However, no difference was observed between SS mushrooms and those trimmed twice (SS2) to the same length. This indicated that the potential increase in ODA that may be produced by the additional tissue damage that probably occurred by cutting the stipes twice, did not result in an increase in the rate of cap opening.

The influence of these stipe trimming treatments on browning rate (decrease in L value) in storage is shown in Figure 5B. The lower initial L in the SS2 mushrooms was probably due to increased handling involved in trimming stipes twice. The reduced rate of browning in storage in the SS and SS2 mushrooms was consistent with previous results (Ajlouni *et al.*, 1992). However, the fact that untrimmed (whole) mushrooms maintained better color in storage than LS mushrooms is unexplained.

Although the exact mechanism by which the shelf life is extended by stipe trimming, especially the reduced rate of browning, is not clear, the results provide experimental evidence that the shelf life of fresh mushrooms can be improved by this harvest practice. However, the yield of saleable mushrooms may be decreased by this practice (Ajlouni, 1991). This reduction in yield would decrease potential revenue for growers unless they receive a differential price for their product based on improvement in initial appearance due to shorter stipes or improved postharvest shelf life resulting

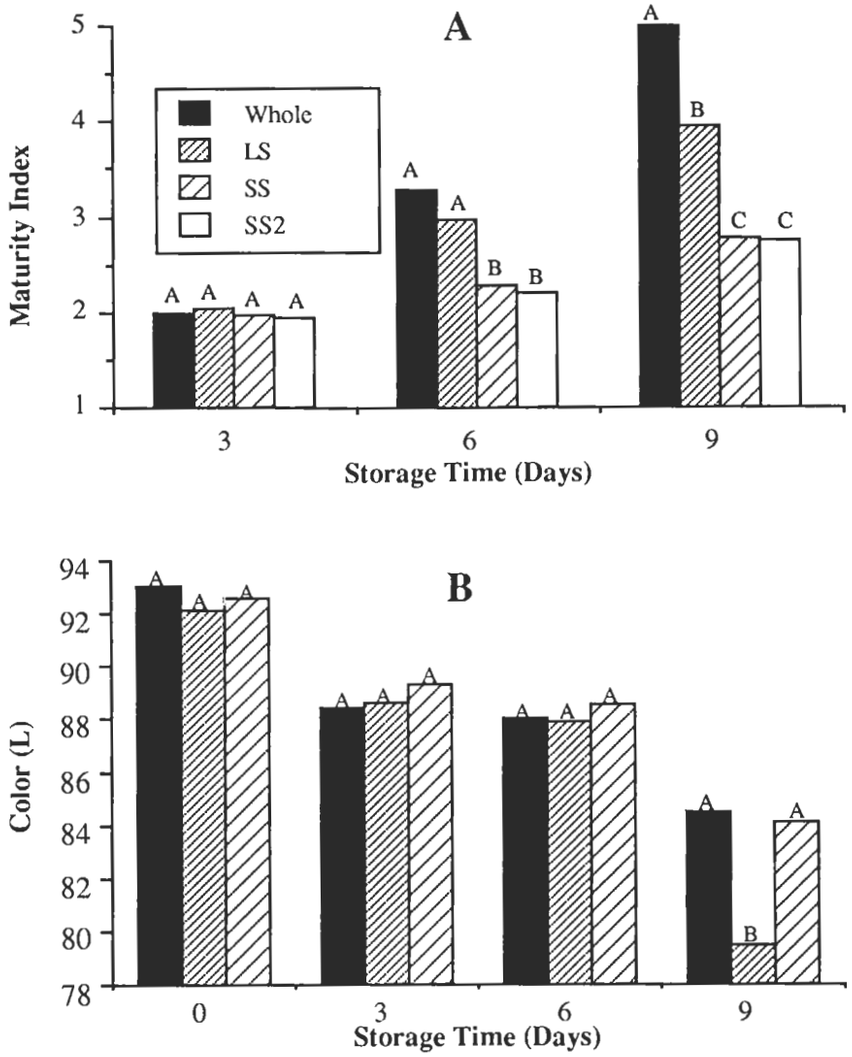


FIGURE 5. Influence of extent of stipe trimming at harvest on postharvest shelf life of mushrooms stored at 13°C in PVC overwrapped packages as indicated by (A) cap development and (B) browning (decrease in L). Whole: whole mushroom picked; LS: trimmed mushroom to long stipe; SS: trimmed mushroom to short stipe; SS2: mushroom trimmed twice.

in greater consumer demand or reduced loss of product in retail markets.

Speculation that quality and shelf life could possibly be improved synergistically by treating irrigation water with calcium chloride and trimming stipes closer at harvest led us to conduct an appropriate experiment to test this hypothesis. The results of this experiment reported by Mau *et al.* (1993b) indicated that both treatments improved shelf life of the harvested mushrooms, and a synergism was evident when both treatments were employed together. Shelf life was dramatically improved by the combination treatment. These results were very encouraging and demonstrate that quality and shelf life of fresh *Agaricus* mushrooms can be improved without expensive or elaborate

procedures or significant reduction in yield.

ACKNOWLEDGMENTS

The authors wish to acknowledge the excellent technical assistance of John Winnett, Linda Scibilia, Tom Rhodes and the MTDF staff. Also, partial financial support from the Pennsylvania Department of Agriculture and the Penn State Mushroom Endowment Fund is gratefully acknowledged.

REFERENCES

AJLOUNI, S.O. (1991). Quality characteristics of two type hybrids of the cultivated mushrooms (*Agaricus bisporus*) and the improvement of their shelf life using stipe trimming and gamma irradiation. Ph.D. Thesis. The Pennsylvania State University.

AJLOUNI, S., BEELMAN, R.B., THOMPSON, D.B. & J.-L. MAU. (1992). Stipe trimming at harvest increases shelf life of fresh mushrooms (*Agaricus bisporus*). *Journal of Food Science* **57**, 1361-63.

BARDEN, C.L., BEELMAN, R.B., BARTLEY, C.E. & SCHISLER, L.C. (1990). The effect of calcium chloride added to irrigation water on quality and shelf life of harvested mushrooms. *Journal of Food Protection* **53**, 759-762.

BARTLEY, C.E., BEELMAN, R.B. & WINNETT, J.R. (1991). Factors affecting color of cultivated mushrooms (*Agaricus bisporus*) prior to harvest and during postharvest storage. *Mushroom Science* **8**, 689-694.

BEELMAN, R.B., BARTLEY, C.E., MAU, J.-L., MIKLUS, M.B., SOLOMON, J.M., ROYSE, D.J., WINNETT, J.R., & MUTHERSBAUGH, H.R. (1992). Irrigation water treatments to improve quality and shelf life of *Agaricus* mushrooms. *Mushroom News* **40**, 18-23.

BEELMAN, R.B., QUINN, J.J., OKEREKE, A., SCHISLER, L.C., MUTHERSBAUGH, H.R. & EVENSEN, K. (1987). Effect of peat casing layer and the addition of calcium chloride to watering treatments on quality and shelf life of fresh mushrooms. *Developments in Crop Science 10, Cultivating Edible Fungi,* pp. 271-282. Edited by P.J. Wuest, D.J. Royse & R.B. Beelman. Amsterdam: Elsevier Science Publishers.

MAU, J.-L., BEELMAN, R.B. & ZIEGLER, G.R. (1992). Effect of 10-oxo-trans-8-decenoic acid on growth of *Agaricus bisporus*. *Phytochemistry* **31**, 4059-4064.

MAU, J.-L., BEELMAN, R.B. & ZIEGLER, G.R. (1993a). Factors affecting 1-octen-3-ol in mushrooms at harvest and during postharvest storage. *Journal of Food Science* **58**, 331-334.

MAU, J.-L., MIKLUS, M.B. & BEELMAN, R.B. (1993b). The shelf life of *Agaricus* mushrooms. In *The Shelf Life of Foods and Beverages*. Edited by G. Charalambous. Amsterdam: Elsevier Science Publishers.

SOLOMON, J.M., BEELMAN, R.B. & BARTLEY, C.E. (1991). Addition of calcium chloride and stabilized chlorine dioxide to irrigation water to improve quality and shelf life of *Agaricus bisporus*. *Mushroom Science* **13**, 695-701.