ELSEVIER

International Biodeterioraton & Biodegradation 43 (1999) 101–107

INTERNATIONAL BIODETERIORATION & BIODEGRADATION

The commercial exploitation of the white rot fungus *Lentinula edodes* (shiitake)

A.C. Campbell*, M. Racjan

Seale–Hayne Faculty of Agriculture, Food and Land Use, University of Plymouth, Newton Abbot, Devon, TQ12 6NQ, UK

Received 16 February 1997; accepted 1 January 1999

Abstract

The Japanese wood mushroom, *Lentinula edodes*, can be cultivated under UK climatic conditions using extensive cultivation systems adapted from traditional growing methods developed in Japan and Taiwan. As well as producing a desirable and high value food product, cultivation offers a viable alternative enterprise for farmers. The growing methods described could provide incentives for the management of broad-leaved woodland in Britain with consequent conservation benefits. Four different strains of *Lentinula edodes* were grown on oak logs under natural environmental conditions below the woodland canopy and fruited in polyethylene tunnels. Yields ranged from 0.5–0.9 kg wet weight shiitake per cordwood log per year over a three year fruiting period.

Keywords: Shiitake; Exploitation; United Kingdom

1. Introduction

The Japanese wood mushroom or shiitake (*Lentinula* [*Lentinus*] *edodes*) is the third most widely cultivated edible mushroom worldwide, surpassed only by *Agaricus spp*. and *Pleurotus spp*. (Chang and Miles, 1991). Shiitake is most commonly grown on felled, aged hardwood logs of oak, beech, chestnut and alder (San Antonio, 1981; Tautorus, 1985) although other hardwood species will support growth (Ito, 1978; Nutalaya and Pataragetvit, 1981; San Antonio, 1981; Przybylowicz and Donoghue, 1990). It is only within the last 60 years that reliable cultivation techniques have been developed with research being initially restricted to Japan, China and Taiwan where *Lentinula edodes* can be found growing naturally. Increasing acceptance for shiitake by western consumers has resulted in the expansion of cultivation areas outside its natural habitat and it is now grown commercially in many countries throughout the world. Shiitake has been adopted as a new crop in the USA following its promotion by Leatham (1982) and experimental and production units have been in operation for some years in Holland, France, Germany and Poland (Campbell and Slee, 1989). Until recently, shiitake, originating from the Far East, was only available in Britain in its dried form and was restricted to specialised retail outlets. The fresh product is now readily available through large supermarket outlets, although lack of production in Britain means that produce must be imported to satisfy the UK demand. Shiitake is valued as a luxury food for its texture and flavour. In addition, it has been shown to have a variety of medicinal and tonic qualities (Przybylowicz and Donoghue, 1990; Buswell and Chang, 1993). Among its medicinal attributes are antitumour activity (Ikekawa et al., 1969; Chihara et al., 1987; Mori et al., 1987; Flynn, 1991), antiviral activity (Tsunoda and Ishida, 1969; Suzuki et al., 1976; Takehara et al., 1979; Tochikura et al., 1987) and cholesterol-lowering activity (Kaneda and Tokuda, 1966; Tokuda et al., 1976; Tokuda and Kaneda, 1979). It is perceived to have aphrodisiac properties (Buswell and Chang, 1993) and there is

* Corresponding author.

0964-8305/99/$ - see front matter
PII: S0964-8305(99)00036-0

anecdotal evidence to suggest it is a cure for gout. It is clear, therefore, that the shiitake mushroom has a number of attributes which make it attractive as a food commodity. Approaches to the commercial exploitation of the mushroom offer the additional benefits of woodland conservation and management, agricultural income and bioconversion of lignocellulosic wastes. Przybylowicz and Donoghue (1990) provide an excellent review of the methods used in cultivation.

Intensive systems use sterilized, enriched sawdust or wood chip substrates managed under controlled conditions (Tautorus, 1985; Campbell and Slee, 1987). Buswell and Chang (1993) advocated this approach as a means of converting organic wastes into edible protein and animal feedstock. This method of cultivation has the major disadvantage of requiring expensive sterilization and environmental control facilities and is, therefore, inappropriate for widespread small-scale application. The alternative and traditional extensive approach investigated in the present study utilizes freshly cut hardwood logs which, once inoculated, are stacked in the woodland during the spawn run period and fruited under semi-controlled conditions in polyethylene tunnels or farm buildings. This approach is low-cost and is appropriate as an alternative enterprise on existing farms that have access to broad-leaved woodland. It has the added advantage of providing an incentive for woodland management to create the conservation benefits that arise from having a much more diverse habitat (Campbell and Slee, 1989). By their nature, extensive systems of production rely on the ability of shiitake strains to colonise hardwood logs and fruit under prevailing climatic conditions. Over 100 different strains of shiitake have been identified and care must be exercised when selecting spawn types. Strains vary in their ability to colonise wood, rate of colonisation, temperature and moisture tolerances, time of fruiting, and quality and quantity of fruit produced, among other things. Strains which perform well on sawdust substrates under controlled conditions might not colonise and fruit on logs and *vice versa*. Spawn commercially available in the UK is primarily sold for these intensive production systems and therefore its reliability on logs cannot be guaranteed. In Japan, the provision of spawn is a highly developed industry and is appropriate to the growing regimes employed there. Spawn available in the USA is derived from Japanese strains and, in most cases, is tried and tested on logs before being made available for use. It is inadvisable to assume that shiitake strains shown to be reliable for production in one situation will perform as well under different conditions. The lack of information relating to shiitake cultivation under UK conditions is a major obstacle to production in Britain.

The present study was undertaken to assess the suitability of selected strains of shiitake for production under an extensive cultivation system with a view to promoting shiitake cultivation as an alternative enterprise for UK farmers.

2. Materials and methods

Sawdust spawn of *Lentinula edodes* strains J1, LE3 and 580 was prepared from cultures maintained on malt extract agar (Oxoid Ltd.) at the Seale–Hayne Faculty. Polypropylene bags were packed with approximately 1.5 kg oak sawdust supplemented with 10% oat bran and adjusted to 60% moisture and were sealed using a polypropylene collar and a cotton wool plug. The substrate was sterilized at 121°C for 1 hour and allowed to cool. A sterile metal rod was introduced into the centre of the sterile sawdust block to create a channel for inoculation. Discs of agar carrying mycelium were aseptically introduced into the channel in such a way as to provide a series of inoculation points throughout the depth of the sawdust block. The bag was resealed, re-plugged and incubated at 22°C for approximately seventy-five days until the substrate was fully colonised with mycelium. This sawdust spawn was used to inoculate logs. Commercially available sawdust spawn (strain 510) was obtained from Mushroom People, Tennesee, USA and was also used for inoculation.

Oak (*Quercus sp.*) logs were felled in January and left to age for at least one month before inoculation. Diameters of the logs varied from 6 to 18 cm and all logs were cut to approximately 1 m in length for ease of handling. Care was taken to keep the bark intact and any damaged logs or logs showing signs of contamination with wild fungi were discarded.

A high speed drill was used to drill 1.5 cm diameter holes approximately 1.5 to 2 cm deep into the logs. The holes were arranged in a diamond formation around the diameter of the log and were approximately 15–25 cm apart. Thus, between 20 and 30 inoculation points per log were achieved. The logs were inoculated by packing sawdust spawn into the holes and the inoculation points were sealed by brushing with hot paraffin wax.

The inoculated logs were kept outdoors below the canopy of a deciduous woodland. They were stacked upright with one end in contact with the soil. The ends of the logs were periodically checked for signs of colonisation and the logs were occasionally inverted. No further management was necessary but weight loss of the reference logs was checked to monitor moisture loss. The logs were left in position until colonisation was complete. Assessment of complete colonisation was either by visual assessment of mycelium development below the bark or by the appearance of 'volunteer' fruit on the logs.

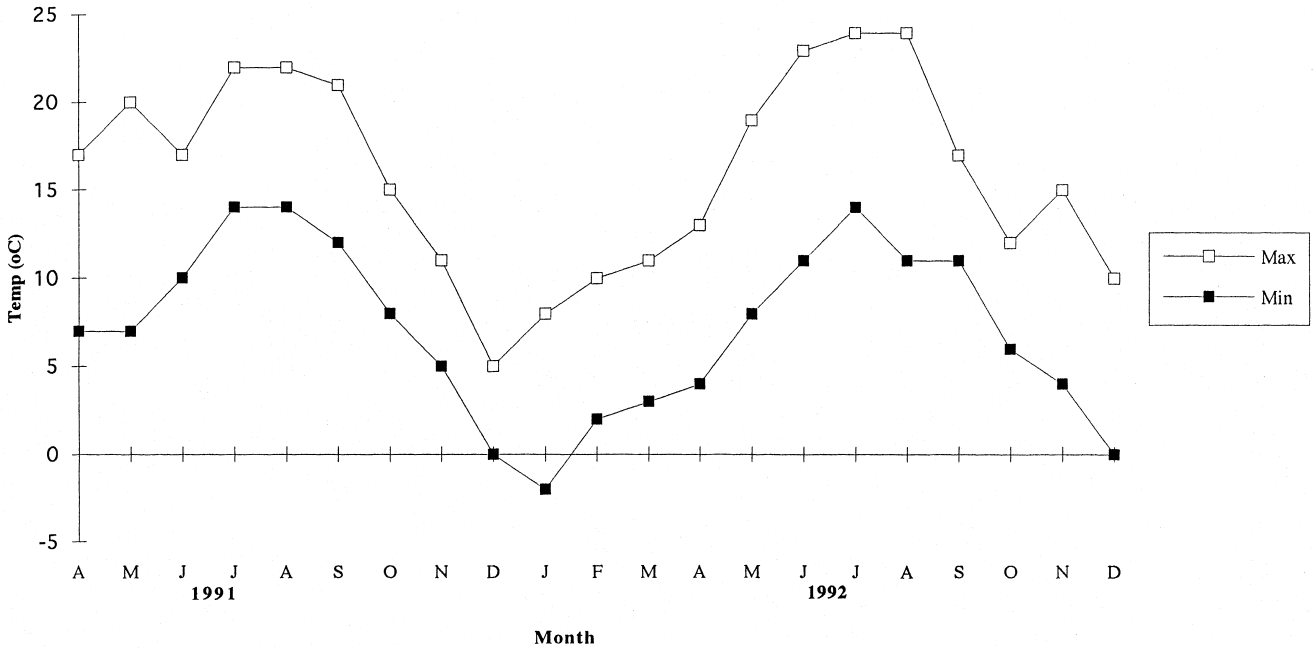

Fig. 1. Average maximum and minimum temperatures in woodland.

When the logs were considered to be fully colonised, batches of logs were immersed in cold water (3–5°C) for 48 hours to induce fruiting. Following immersion, they were arranged in rows held upright in a polyethylene tunnel and fruit bodies were harvested as required over a 'flush period' of 14–74 days. Water was sprayed on the floor of the fruiting tunnel during periods of high temperature to maintain high humidity and reduce the temperature to below 24°C for fruiting. When fruiting was complete, the logs were returned to the woodland and allowed to 'rest' for at least one month before the fruiting cycle was repeated. Times of fruiting and treatment of logs in batches was organised in such a way as to satisfy demand for the product and to be realistic in a typical commercial situation.

3. Results

Air temperatures measured in the woodland ranged from −2°C to 24°C during the spawn run period (Fig. 1). Air temperatures in the polyethylene fruiting tunnel ranged from 5°C to 26°C and relative humidity from approximately 70% to 100%.

It was realistic to regard the years 1992 to 1994 as the fruiting period for all strains tested, although significant mushroom production began only during the last four months of 1992.

Logs inoculated with strain 510 in March 1991 were dipped following the appearance of volunteer mushrooms in November 1991. At this stage, dipping did not induce significant fruiting and only a few mushrooms from a few logs were harvested in the latter months of 1991. The strain continued to produce mushrooms at a low level for the first eight months of 1992 before significant quantities were produced from September 1992 [Fig. 2(a)]. Thus, under the conditions of this investigation, reliable and significant fruiting was not achieved until 18 months after log inoculation. Strain 510 produced a total average yield per log of

Table 1
Yield of shiitake (wet wt.) grown on oak logs

Strain	*n*	Inoculation	kg wet wt. shiitake						
			1991	1992	1993	1994	Total	Ave yield/log	Ave. yield/log/yr
510	107	March '91	0.1	56	118	70	244.1	2.3	0.8
LE3	77	June '91		14	131	60	205	2.7	0.9
580	67	May '91		2	24	80	106	1.6	0.5
J1	60	Feb '91		2	34	48	84	1.4	0.5
Total	311		0.1	74	307	258	639.1		

2.3 kg wet weight of shiitake over the period 1992 to 1994 (Table 1). Peak production from strain 510 occurred between April and September 1993, approximately 25 months after inoculation. A total of 118 kg wet weight shiitake was harvested from 107 oak logs (average yield of 1.1 kg wet weight per log) during the peak year, 1993. An average yield of 0.8 kg wet weight shiitake per log per year was achieved over the three year fruiting period investigated (Table 1).

Strain LE3, inoculated in June 1991, reached peak production in March 1993, 25 months after inoculation and produced an average yield of 1.7 kg wet weight shiitake per log in 1993 [Fig. 2(b)]. The average yield per log over the three year production period was 2.7 kg wet weight shiitake (0.9 kg wet weight shiitake per log per year) (Table 1).

Strain 580 did not begin to produce shiitake until November 1992 and then only at low levels. Peak production for this strain occurred from 34 months after inoculation, and 80 kg shiitake was produced from 67 logs (average yield of 1.2 kg wet weight shiitake per log) during the peak production period of 1994. The average yield per log per year over the three year fruiting period was lower for strain 580 than either 510 or LE3 (Table 1). The fruiting pattern of strain J1 was similar to that of strain 580 [Fig. 2(c,d)]. There was no

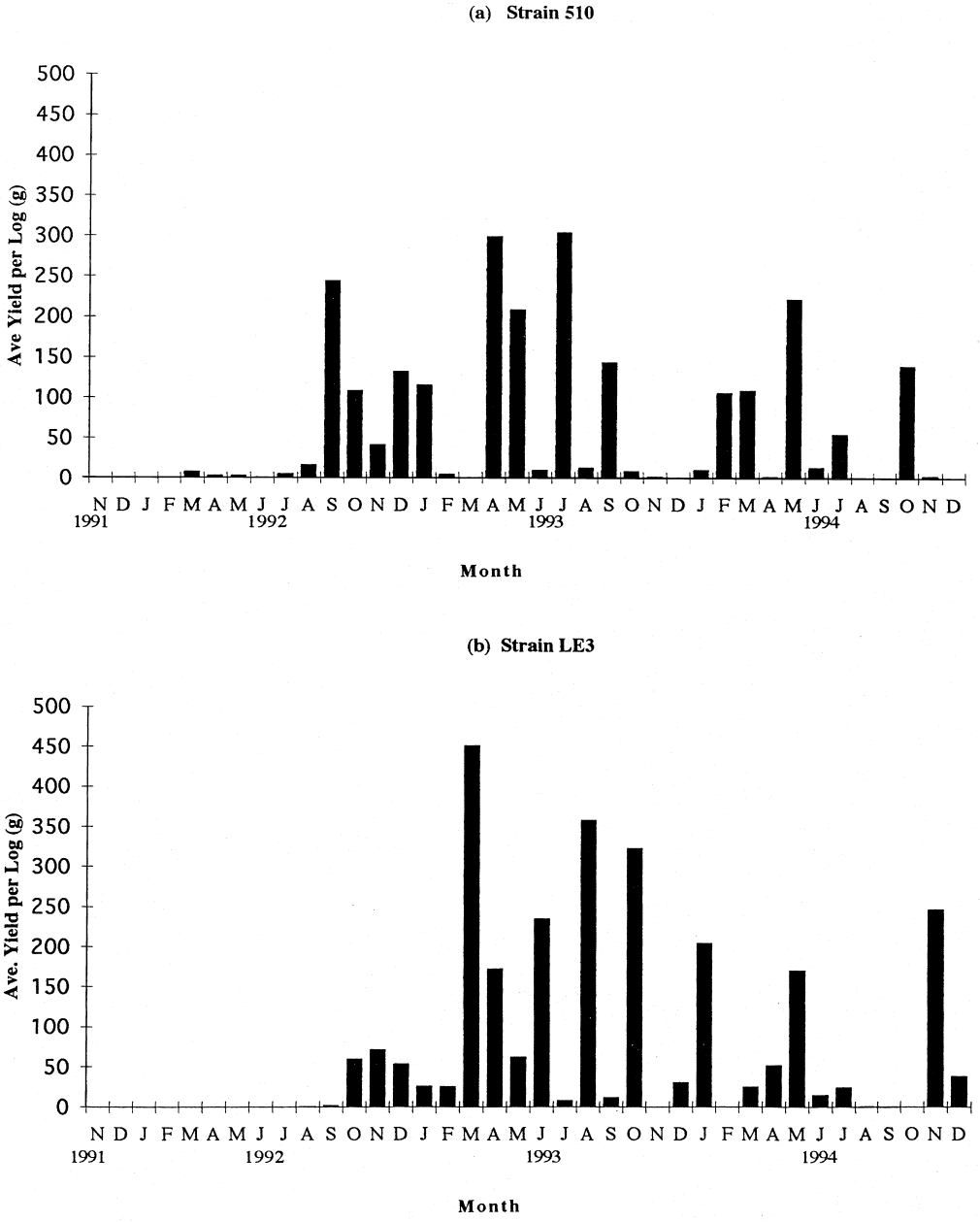

Fig. 2. Average monthly production of shiitake (wet wt.) per oak log: (a) Strain 510, (b) Strain LE3, (c) Strain 580, (d) Strain J1.

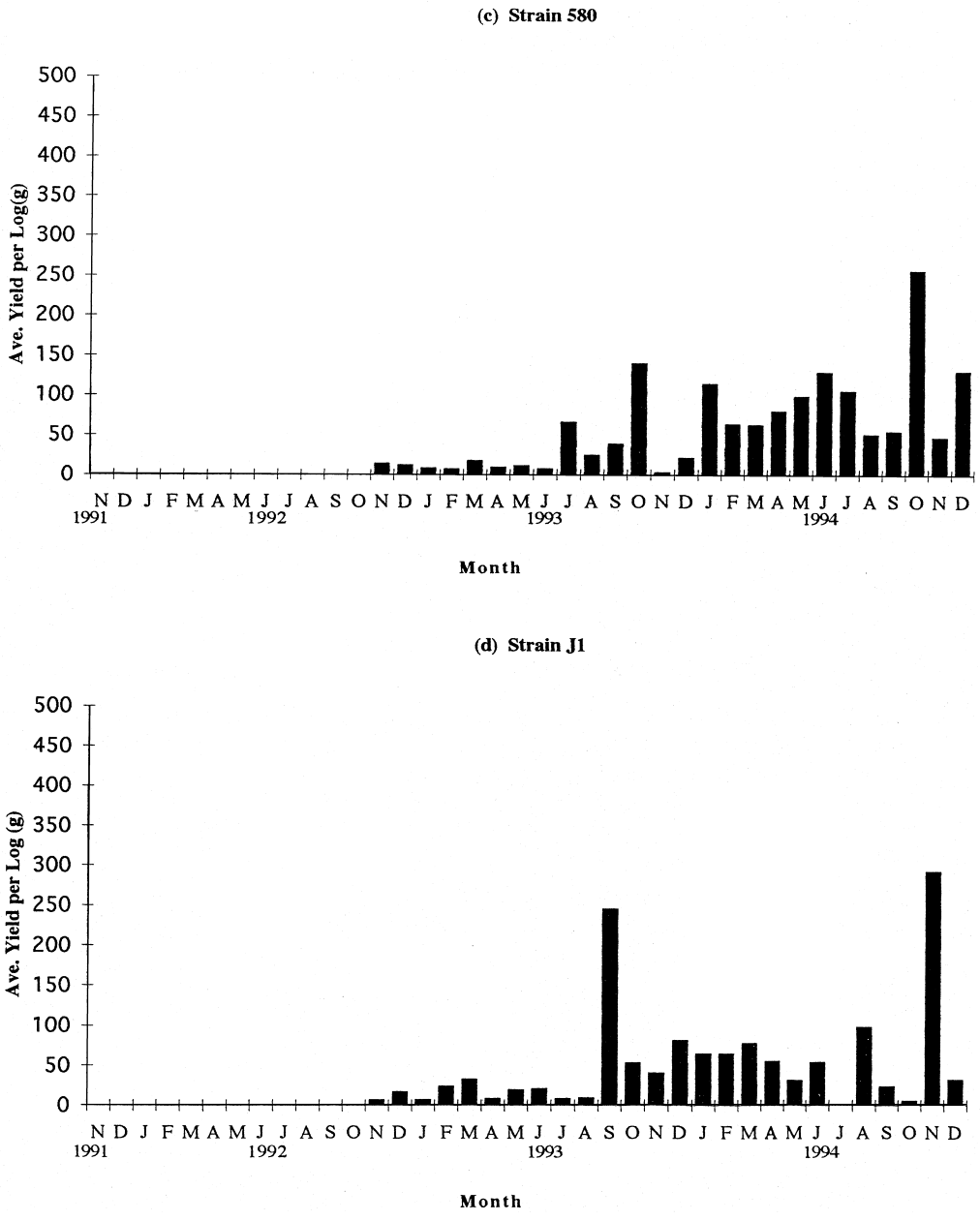

Fig. 2 (*continued*)

evidence of seasonality of fruiting and, with fruiting being controlled by dipping, year-round production was possible.

4. Discussion

The results of this study have shown that the shiitake mushroom can be grown under UK climatic conditions on readily available oak logs in a low-cost, semi-controlled production system.

It has been recognised (Przybylowicz and Donoghue, 1990) that temperature is one of the most important factors in shiitake cultivation. The optimum temperature for mycelium growth is about 25°C. Below 5°C and above 35°C, mycelial growth stops (Tokimoto and Komatsu, 1978). Shiitake has been reported to survive in logs at temperatures as low as −30°C, whereas mycelium is killed above 45°C (Przybylowicz and Donoghue, 1990). San Antonio (1981) reported that high (35°C) and low (−7°C) temperatures restricted mushroom production in American trials resulting in seasonal production of shiitake. Temperatures in the current investigation ranged from −2°C to 24°C in the woodland. Although not reaching the optimum temperature for mycelium growth, the

temperate UK climate is unlikely to have a strong influence on restricting production except in extreme years. No seasonal effects were found in the present study.

Commercially available shiitake strains differ in their performance in relation to temperature and are marketed as wide-range strains, warm-weather strains or cold-weather strains. Strain 510 was known to be a wide-range strain suited to the production system used. It was marketed as a strain which fruits 4.5–5 months after inoculation. In the current investigation, first fruit appeared 8 months after inoculation, but it was not until 18 months after inoculation that significant quantities of mushrooms were produced. It is likely that the temperatures experienced during the incubation period were lower than those which might be expected in the USA or Japan and thus reduced the rate of spawn run. Heaviest yields were produced during the second year of fruiting and this was consistent with a wide-range strain (Przybylowicz and Donoghue, 1990). Strain LE3 behaved in a similar manner to strain 510 with peak yields in the second year of fruiting. In contrast, strains 580 and J1 produced peak yields in the third year of fruiting, which were consistent with cold-weather strains. The quality of mushrooms produced by all strains was considered to be more than acceptable and there were differences in size, shape, thickness of cap and colour between strains.

Yield data should be interpreted with caution. The wet weight of mushrooms produced was influenced by the stage of maturity and thus the size of the mushroom and its water content. Watering of logs during fruiting increases the weight of the fruit and also may affect fruit quality. Mushrooms recognised by the Japanese as premium quality, or Donko, are produced during cool, dry conditions and have a low moisture content. Although the term Donko traditionally applies to dried shiitake, there was evidence that fruits similar to Donko quality were produced at times when humidity and temperature were low in the fruiting tunnel. These mushrooms were lighter in weight than more typical mushrooms of similar size. Weight data do not necessarily reflect all considerations in mushroom production. Harvesting and weight measurement in the present investigation was organised in such a way as to be appropriate to a typical commercial enterprise, and no grading of produce was undertaken. Quality was determined as being that which was acceptable to the purchasers. Mushrooms were picked at various stages of maturity ranging from those with the veil intact to fully open fruits. Within limits, there is no recognition of different qualities in the current UK market.

Accepting the limitations of weight data, strain LE3 was the best strain examined producing an average of 0.9 kg shiitake per log per year, equivalent to 289.38 g fresh weight/kg oak at spawning. In a similar study, San Antonio (1981) reported a maximum yield of 139 g fresh weight/kg wood at spawning. The difference between the trails might suggest that the ability to produce mushrooms year round in the UK allows higher yields than those possible in the USA, although different strains and conditions were used so the trials are not directly comparable.

This investigation was concerned with mushroom production over a three year period. The logs investigated continue to produce fruit and the maximum production period is expected to be 5–6 years depending on the size and condition of logs. It is likely that yields will decrease towards the end of the life of the log.

The value of the shiitake produced, as sold through specialised hotel markets, was approximately £15 per kg. A total fresh weight of 639 kg of shiitake was produced from 311 logs over the three year fruiting period. The gross value of shiitake produced was, therefore, £9585 or £30.80p per log. It would be realistic for a small farmer undertaking shiitake production, as an alternative enterprise, to manage around 500 logs per year. The results of this investigation suggest that the gross value of the products in such an enterprise could be approximately £1363, £12759 and £5844 in the second, third and fourth years, respectively. This would be increased if 500 logs were inoculated annually. This value is dependent on the market and it is recognised that marketing, as currently organised in the UK, is a major obstacle to realising this potential. It is expected that markets will improve as acceptance and knowledge of this mushroom increase among the general public.

References

Buswell, J.A., Chang, S.T., 1993. Edible mushrooms: attributes and applications. In: Chang, S.T., Buswell, J.A., Miles, P.G. (Eds.), Genetics and Breeding of Edible Mushrooms. Gordon and Breach Science Publishers, Reading, pp. 297–324.

Campbell, A.C., Slee, R.W., 1987. Commercial cultivation of shiitake in Taiwan and Japan. Mushroom Journal of the Tropics 7, 127–134.

Campbell, A.C., Slee, R.W., 1989. The introduction of *Lentinus edodes*, the Japanese wood mushroom, to the UK. Nature in Devon 10, 25–33.

Chang, S.T., Miles, P.G., 1991. Recent trends in world production of cultivated mushrooms. The Mushroom Journal 503, 15–18.

Chihara, G., Hamuro, J., Maeda, Y.Y., 1987. Anti-tumour and metastasis: inhibitory actions of lentinan as an immunomodulator. Cancer Detection and Prevention Supplement 1, 423–443.

Flynn, V.T., 1991. Is the shiitake mushroom an aphrodisiac and a cause of longevity? In: Maker, M.J. (Ed.), Science and Cultivation of Edible Fungi. Balkema, Rotterdam, pp. 345–361.

Ikekawa, T., Uehara, N., Maeda, Y.Y., Nakamishi, M., Fukuoka, F., 1969. Antitumour activity of aqueous extracts of some edible mushrooms. Cancer Research 92, 734–735.

Ito, T., 1978. Cultivation of *Lentinus edodes*. In: Chang, S.T., Hayes, W.A. (Eds.), The Biology and Cultivation of Edible Mushrooms. Academic Press, London, pp. 461–473.

Kaneda, T., Tokuda, S., 1966. Effects of various mushroom preparations on cholesterol levels in rats. Journal of Nutrition 90, 371–376.

Leatham, G.F., 1982. Cultivation of shiitake, the Japanese forest mushroom, on logs: potential industry for the United States. Forest Products Journal 32 (8), 29–35.

Mori, K., Toyomasu, T., Nanba, H., Kwoda, H., 1987. Antitumour activity of fruit bodies of edible mushrooms orally administered to mice. Mushroom Journal of the Tropics 7, 121–126.

Nutalaya, S., Pataragetvit, S., 1981. Shiitake cultivation in Thailand. Mushroom Science 11, 723–737.

Przybylowicz, P., Donoghue, J., 1990. Shiitake Growers Handbook. The Art and Science of Mushroom Cultivation. Kendall/Hunt Publishing Company, Iowa.

San Antonio, J.P., 1981. Cultivation of the shiitake mushroom, *Lentinus edodes*. Hort. Science 16 (2), 151–156.

Suzuki, F., Koide, T., Tsunoda, A., Ishida, N., 1976. Mushroom extract as an interferon inducer. I. Biological and physiochemical properties of spore extracts of *Lentinus edodes*. Mushroom Science 9 (1), 509–520.

Takehara, M., Kuida, K., Mori, K., 1979. Antiviral activity of virus-like particles from *Lentinus edodes* (shiitake). Archives of Virology 59, 269–274.

Tautorus, T.E., 1985. Mushroom fermentation. Advances in Biotechnological Processes 5, 227–273.

Tochikura, T.S., Nakashima, H., Kaneko, Y., Kobayashi, N., Yamamoto, N., 1987. Suppression of human immuno-deficiency virus replication by 3′-azido-3′deoxythymidine in various human haematopoietic cell lines: Augmentation of the effect of lentinan. Japanese Journal of Cancer Research (Gann) 78, 583–589.

Tokimoto, K., Komatsu, M., 1978. Biological nature of *Lentinus edodes*. In: Chang, S.T., Hayes, W.A. (Eds.), The Biology and Cultivation of Edible Mushrooms. Academic Press, London, pp. 445–449.

Tokuda, S., Kaneda, T., 1979. Effect of shiitake mushrooms on plasma cholesterol levels in rats. Mushroom Science 10, 793–796.

Tokuda, S., Tagiri, A., Kano, E., Sugawara, Y., Suzuki, S., Sato, H., Kaneda, T., 1976. Reducing mechanism of plasma cholesterol by shiitake. Mushroom Science 9 (1), 445–462.

Tsunoda, A., Ishida, N., 1969. A mushroom extract as an interferon inducer. Annals of The New York Academy of Science 173, 719–726.