**Martínez-Carrera, D**., A. Aguilar, W. Martínez, M. Bonilla, P. Morales & M. Sobal, 2000. Commercial production and marketing of edible mushrooms cultivated on coffee pulp in Mexico. Chapter 45, pp. 471-488. *In*: Sera, T., C. Soccol, A. Pandey & S. Roussos (Eds.). *Coffee biotechnology and quality*. Kluwer Academic Publishers, Dordrecht, The Neterhlands. ISBN 0-7923-6582-8.

# Commercial production and marketing of edible mushrooms cultivated on coffee pulp in Mexico

D. Martínez-Carrera, A. Aguilar, W. Martínez, M. Bonilla, P. Morales and M. Sobal

College of Postgraduates in Agricultural Sciences, *Campus* Puebla, Mushroom Biotechnology, Apartado Postal 701, Puebla 72001, Puebla, Mexico. Fax: 22-2852162; dcarrera@colpos.colpos.mx.

**Key words**: Coffee pulp, sustainable agriculture, mushroom biotechnology, *Pleurotus*, *Lentinula*, *Auricularia*, Mexico.

**Running title**: Mushroom cultivation on coffee pulp.

Corresponding author: D. Martínez-Carrera
College of Postgraduates in Agricultural Sciences
Mushroom Biotechnology
Apartado Postal 701
Puebla 72001, Puebla, Mexico
Fax: 22-2852162; dcarrera@colpos.colpos.mx

**Contents**

## I. Introduction

Large-scale utilization and management of coffee pulp around the world still remains as a challenge for the 21st century. Several alternatives have been studied, such as silage, aerobic composting, biogas production, vermiculture, animal feed (cattle, porks, chickens, fishes), and production of ethanol, vinegar, single-cell protein, enzymes, biopesticides, and probiotics (Braham & Bressani, 1979; Adams & Dougan, 1981; Roussos *et al*., 1991; Soccol *et al*., 1999). Although these processes are feasible in the laboratory or at small scale, successful technology transfer programmes are limited. Most efforts have focused on coffee growers, who have normally failed in taking advantage of technologies which are quite challenging, time-consuming, and technically very demanding.

We explore another alternative which considers the development of an agro-industry parallel to and connected with coffee production (Martínez-Carrera *et al*., 1998). In this case, efforts are concentrated on entrepreneurs capable of managing mushroom biotechnology, capital investment from other sectors of the economy, and the market in a regional or world context.

## II. Importance of mushroom biotechnology

Mushrooms are fleshy, spore-bearing reproductive structures of fungi. For a long time, wild edible mushrooms have played an important role as a human food. However, empirical methods for their cultivation are relatively recent (Martínez-Carrera, 2000). They were independently developed in China about 1,000 years ago for *Auricularia* spp. and *Lentinula edodes* (Berk.)Pegler, and in France about 350 years ago for *Agaricus bisporus* (Lange)Imbach. During the last 50 years, these methods have been significantly improved and modern technologies permit the cultivation of about 20 species at different levels around the world (Chang & Miles, 1989).

Recent figures indicate that commercial production of fresh edible mushrooms is a rapidly-growing industrial activity (Chang & Miles, 1991). During the period 1990-1994, world mushroom production increased by 30.5%, reaching about 4,909 thousand tons in 1994. The global economic value, although difficult to evaluate, has been estimated to be more than 9.8 billion dollars per annum (Chang, 1996). These data include several species of eleven main genera: *Agaricus*, *Lentinula*, *Volvariella*, *Pleurotus*, *Auricularia*, *Flammulina*, *Tremella*, *Hypsizygus*, *Pholiota*, *Grifola*, and *Hericium*. Mushrooms belonging to the genus *Agaricus* are the most widely cultivated, and their total global production in 1994 was 1,846 thousand tons fresh weight.

The biodegradation of lignocellulosic by-products from agriculture or forestry confers ecological importance on mushroom cultivation (Wood, 1985). To achieve this, mushroom hyphae (*i.e*., mycelium) produce a wide range of extracellular enzymes capable of degrading complex organic material (Martínez-Carrera, 2002). Millions of tons of these by-products, which otherwise would remain unused, are recycled every year as substrates for mushroom growing. The resulting so-called spent substrate is less bulky, and has been traditionally used as a soil conditioner by farmers and gardeners. However, recent studies have shown that spent mushroom compost can also be used for growing containerised nursery plants (Maher, 1991), or as a potential animal feed (Grabbe, 1990). The nutrient needs of maize crops can be satisfied if 200-400 tons/acre of spent mushroom compost are incorporated into the soil, without the negative consequence of adding nitrate to either surface or field drainage water (Flegg, 1991).

Mushroom cultivation is an efficient and relatively short biological process of food protein

recovery from lignocellulosic materials. The protein content of edible mushrooms can be considered as their main nutritional attribute. An average value of 19-35% on a dry weight basis has been reported (4% on a fresh weight basis), as compared to 13.2% in wheat, and 25.2% in milk. Edible mushrooms are also a good source of some vitamins and minerals, although fat, carbohydrate, and dietary fibre contents are comparatively low. Recent research work indicates medicinal attributes in several species, such as antiviral, antibacterial, antiparasitic, antitumor, antihypertension, antiatherosclerosis, hepatoprotective, antidiabetic, anti-inflammatory, and immune modulating effects (Wasser & Weis, 1999). Mushrooms are now considered as genuine nutraceuticals, from which nutriceuticals and pharmaceuticals can be developed. Overall value of mushroom products obtained from mushrooms is rapidly increasing, and it has been estimated to be about 3.6 billion dollars per annum (Chang, 1999).

## III. Principles of mushroom biotechnology

In general, there are three major fundamental technologies involved: 1) Spawn technology, 2) Mushroom production technology, and 3) Processing technology (Martínez-Carrera, 1999b; Fig. 1). A variety of methods and techniques have been developed and described in detail for each technology (Flegg *et al*., 1985; Chang & Miles, 1989; van Griensven, 1988).

Spawn technology includes the isolation of strains from wild mushrooms growing in nature (Fig. 2a), either by tissue culture or spore culture (Fig. 2b-d). Intensive selection and breeding through classical and molecular genetics is necessary, as wild strains are normally not suitable for commercial cultivation. Genetic improvement is focused on high-yielding strains having additional characteristics, such as disease/chemical resistance, earliness, tolerance to low or elevated temperatures, as well as shape, taste, and colour of fruit bodies (Fig. 2e). When a selected strain is available, spawn preparation is carried out using cereal grains (*e.g*., wheat, rye, millet, rice, sorghum) or other organic substrates (*e.g*., coffee pulp, straw, cotton waste, sawdust) sterilized in glass jars or polypropylene plastic bags (Fig. 3a). These organic materials are inoculated, and incubated to be completely colonized by the mushroom mycelium and then used as spawn (Fig. 3b-d).

Mushroom production technology starts with construction of the farm, according to local environmental conditions and species requirements. Suitable substrates are then prepared using organic raw materials, easily available at low costs in each region. These substrates, selective for mushroom growing, are spawned and incubated in the farm. Production of fruit bodies varies according to each species, spawn quality, substrate quality, and environmental conditions.

Processing technology is fundamental for commercial production and requires specific facilities. After harvesting, mushrooms are normally cooled down to retard fruit-body metabolism, and then sent to the fresh market. Alternative methods are available, such as cooling, vacuum cooling, cooling with positive ventilation, and ice-bank cooling with positive ventilation. Further processing, *e.g.* canning, drying, or irradiation, can also be carried out depending on marketing strategies.

## IV. Mushroom cultivation on coffee pulp

Historical records suggest that coffee was introduced to Mexico around 1790. Coffee cherries have mainly been processed by the method of wet process ever since, and coffee pulp discarded causing insalubrious conditions and pollution in nearby rivers. Coffee pulp has also been

exposed to a variety of microorganisms naturally occurring in the environment. A new ecological niche was then available for native strains of edible oyster mushrooms (*Pleurotus*), primary decomposers having the ability of degrade lignocellulose (Fig. 2a). In 1982, isolation and characterization of *Pleurotus* strains capable of growing on sterilized coffee pulp were reported (Martínez-Carrera & López, 1982; Martínez-Carrera, 1984; Martínez-Carrera *et al*., 1984). This was followed by a series of studies which have shown that coffee pulp, either as a sole substrate or mixed with other organic materials, is a good substrate for cultivation of the edible mushrooms *Pleurotus*, *Lentinula*, and *Auricularia* (Fig. 4a-c; Table 1).

**a) Substrate preparation**

Fresh coffee pulp produced by wet processing is immediatly subjected to microbial degradation, as yeast (60.6%), fungal (2.4%), and bacterial (37%) populations occur naturally (Gaime-Perraud *et al*., 1993). Natural fermentation develops rapidly following different pathways (*e.g*., acetic, lactic, anaerobic, aerobic), depending on physical, chemical, biological, and environmental factors. For these reasons, coffee pulp should be managed appropriately and pretreated in order to be used as substrate for mushroom growing.

Fresh coffee pulp is allowed to drain for 4-8 hours in order to reach 60-80% moisture content, and piled up into long pyramidal heaps (*ca*. 1 m high x 1.5 m wide at the base). An efficient aerobic fermentation should be promoted by turning the pile every three days (about 4-6 tonnes can be turned in one man-day) [Fig. 5a]. Coffee pulp fermented for up to 10 days has good structure and consistency, and can be used for *Pleurotus* cultivation. After fermentation, coffee pulp is relatively odourless, less bulky, and physically and chemically more homogeneous. Its pH (6.0-7.0) remains suitable for mycelial growth, and mushroom yields are slightly higher (Table 2). Coffee pulp can also be mixed or supplemented with other agricultural by-products to favour aerobic fermentation, such as straw (barley, wheat), maize stubble, and sugar cane bagasse.

Caffeine causes adverse effects in animal metabolism. Caffeine content in the coffee pulp varies during mushroom cultivation (Table 3). The highest reduction takes place during substrate preparation by aerobic fermentation and pasteurization (immersion in hot water at 70°C for 15 min). Caffeine reduction during mushroom cultivation (*i.e.*, mycelial growth, fruiting, harvesting) is not significant. This is supported by laboratory experiments, in which mycelial growth on agar plate is gradually inhibited at caffeine concentrations ranging from 0.250-2.0 mg/ml (Martínez-Carrera *et al*., 1988).

After drainage, uniform solar drying of coffee pulp is possible in 4-6 days if environmental conditions are suitable (Fig. 5b). Dry coffee pulp can be stored, and used for *Pleurotus* cultivation even after two years without significant variations in mushroom yields (Table 4). Large-scale artificial drying of fresh coffee pulp is also possible taking advantage of facilities available within coffee regions. Drained coffee pulp is loaded in a commercial coffee drier, having a gas burner and a fan (Fig. 5c). Each load of about 5,000 kg can be dried at 80°C for 30 h. There is no significant difference between fresh and dry coffee pulp in terms of general characteristics (Table 5), as they contain similar amounts of organic matter, nitrogen, phosphorus, potassium, calcium, magnesium, and a pH slightly acid (Martínez-Carrera *et al*., 1996b). Dry coffee pulp can be used for mushroom cultivation without previous aerobic fermentation.

Dry coffee pulp also offers transportation advantages, as it is less bulky and has a higher water retention capacity. For example, 1 $m^3$ of dry coffee pulp has about 136 kg, while 1 $m^3$ of wheat straw (a substrate commonly used for large-scale mushroom cultivation in Mexico)

has around 70 kg. This means that one lorry transporting 18,000 kg of dry coffee pulp is equivalent to 4.4 lorries of wheat straw. In addition, dry coffee pulp increases its weight about 275% when rehydrated, while wheat straw increases around 200% (Martínez-Carrera *et al*., 1996b).

**b) Substrate pasteurization or sterilization**

After fermentation or rehydration, coffee pulp (as a sole substrate, mixed or supplemented with other organic materials) should pasteurized for the cultivation of *Pleurotus* (Martínez-Carrera, 1987; 1989), while sterilized for growing *Lentinula* and *Auricularia*. Coffee pulp can be pasteurized by immersion in hot water at 70º-90ºC for 1-2 hours, a method suitable for rural mushroom cultivation on a small scale (Fig. 5d). For large-scale processing, coffee pulp is placed in an appropriate room or tunnel and pasteurized with steam at 60º-100ºC for 6-24 hours. In the case of substrate sterilization, coffee pulp is introduced into polypropylene plastic bags, and autoclaved at 100º-121ºC for 1-2 hours (Martínez-Carrera, 1998).

**c) Spawning**

Appropriate mushroom strains should be selected according to local environmental conditions, considering that coffee plantations occur at a variety of altitudes (300-1,400 m).

Pasteurized coffee pulp is cooled, and homogeneously inoculated with the spawn (*Pleurotus*), either by hand or mechanically, at a rate ranging from 0.5-3% of fresh substrate weight (Fig. 6a-d). In the case of substrate sterilization, the inoculation of supplemented coffee pulp is carried out at a similar spawning rate (*Lentinula*, *Auricularia*) under aseptic conditions in a laboratory.

**d) Production systems**

Coffee pulp spawned with *Pleurotus* species is introduced in plastic bags of different sizes, although trays, shelves, vertical plastic sacks, and pressed rectangular blocks may also be used. Inoculated containers (*Pleurotus*, *Lentinula*, *Auricularia*) are placed in growing rooms for incubation and/or fruiting, where temperature (15º-30ºC), relative humidity (> 60%), ventilation, and light should be as stable as possible for mushroom cultivation (Martínez-Carrera, 1987; Martínez-Carrera *et al*., 1992a). Complete colonization of coffee pulp by the mushroom mycelium normally takes 25-30 days for *Pleurotus*, while 60-120 days for *Lentinula* and *Auricularia*. After this incubation period, main environmental factors are managed to promote fruiting. Differentiation starts with formation of small structures called primordia, and complete fruit-body development takes 4-7 days (Fig. 6e-g). Mushroom yields vary according to biological factors, environmental conditions, as well as pests and diseases present during cultivation (Figs. 6h, 7a-b). The biological efficiency, defined as the yield of fresh fruit bodies as a percentage of the dry weight of substrate at spawning (Tschierpe & Hartmann, 1977), varies from 89-175% in *Pleurotus*, from 20-37% in *Auricularia*, and is higher than 21% in *Lentinula*.

In subtropical regions, fresh mushrooms should be cooled down or processed further in order to avoid rapid deterioration before marketing (Fig. 7c). Mushroom canning using local recipes allows to produce a commercial product which is safe, stable, economic, and with good sensory and nutritive properties (Fig. 7d). This processing technology also permits to increase the value added to mushrooms, to standardize mushroom quality, to highlight certain culinary properties of mushrooms by good recipes, and to develop marketing strategies at a national or international level (Martínez-Carrera *et al*., 1996a).

**e) Spent coffee pulp**

After mushroom cultivation, a proportion of about 27% from the original substrate will remain. Approximate chemical composition of spent coffee pulp, after *Pleurotus* cultivation, is shown in Table 6. Carbohydrates (29.9%), crude protein (21.5%), crude fat (1.8%), and crude fibre (31.4%) are main components present. This spent substrate can be composted, either aerobic composting or vermicomposting, to produce an organic fertilizer or soil conditioner for crop soils (Fig. 8a-b).

**f) Socioeconomic aspects**

Social, economic, and ecological benefits can be obtained through mushroom biotechnology using coffee pulp as a growing substrate (Martínez-Carrera, 1989a, 1999b; Martínez-Carrera & Larqué-Saavedra, 1990; Martínez-Carrera *et al*., 1991a,b; 1993; 1992a, b; 1995; 1998). Main production and operation costs from commercial and rural production of edible mushrooms are salaries (48.3%; five workers), raw materials and energy (33.6%), travelling expenses (5.5%), maintenance (6.8%), and regional marketing (3.3%) [Table 7]. A cost-benefit analysis of a mushroom farm operating commercially indicates that this biotechnological process is profitable, even under rural conditions (c/b ratio= 1.10) [Table 8]. In comparison with other crops and agro-industries, mushroom cultivation is also an efficient process for using and converting energy or water into a human food. Water consumption is considerably higher in mushroom production (*ca*. 97%) than in spawn production (*ca*. 3%). Overall data show that 28 L of water are required for producing 1 kg of fresh oyster mushrooms using rustic technologies, in a considerably short period of time (25-30 days after spawning). This is a smaller amount in comparison with estimations for other foods or forages, such as potatoes (500 L/kg), wheat and alfalfa (900 L/kg), sorghum (1,110 L/kg), corn (1,400 L/kg), rice (1,912 L/kg), soybeans (2,000 L/kg), broiler chicken (3,500 L/kg), and beef (100,000 L/kg). The production of 1 kg of beef requires 3,571 times more water than the amount needed to produce 1 kg of oyster mushrooms (Table 9). Several environmental, economic, and social indicators have been identified and interpreted to assess sustainability of rural mushroom cultivation (Table 10).

## V. Future and prospects

Mushroom cultivation is a well-established and profitable biotechnological process carried out worldwide on a large or small scale. Coffee pulp, either as a sole substrate or supplemented with other organic materials, can be used as a substrate for growing the edible mushrooms *Pleurotus*, *Lentinula*, and *Auricularia*. However, utilization of fresh coffee pulp is limited due to: 1) Seasonal availability during the year, 2) Active natural fermentation, 3) Impractical and uneconomic transportation, and 4) Large-scale handling for substrate preparation is more demanding and laborius, in comparison with other agricultural by-products (*e.g*., straw and corn stubble). Accordingly, at present, the establishment of a mushroom farm within a coffee region, as an independent industry connected with regional agricultural activities (*i.e.*, agro-industry), is a realistic alternative for large-scale utilization of fresh coffee pulp. Appropriate regional adaptations are necessary to design the mushroom farm, considering strain selection, spawn preparation, substrate availability, spawning, production systems, fruiting, and post-

harvest processing. The sustainable model for rural production of edible mushrooms represents a strategy that allows large-scale, small-scale, and domestic cultivation to promote regional development (Martínez-Carrera *et al*., 1998). Associations of coffee growers and mushroom producers may be a productive alternative, as long as enough financial and technical assistance is available and appropriate marketing strategies developed.

Dry coffee pulp can also be used for mushroom cultivation (Martínez-Carrera *et al*., 1996b). However, solar drying is inefficient for processing large amounts, time-consuming, and dependent on environmental conditions, while artificial drying is more expensive. Dry coffee pulp has several advantages: water retention capacity, homogeneity, physico-chemical structure, practical transportation, and availability throughout the year. Although production costs are relatively higher, in comparison with other agricultural by-products, dry coffee pulp represents a high quality raw material. Enough capital investment is necessary to develop an efficient technology for large-scale processing, in which dry coffee pulp can be stored in appropriate silos to be marketed worlwide as a supplement for substrate formulations in order to improve yields in the mushroom industry.

Further research work may be focused on testing other methods of coffee pulp preservation, such as ensiling, for mushroom cultivation. Coffee pulp can also be studied as a substrate for other cultivated species of edible mushrooms. Increasing importance of organic coffee in the world market will benefit mushroom cultivation, as the coffee pulp produced would permit the production of organic mushrooms.

## VI. References


Adams, M. R. & J. Dougan, (1981), Biological management of coffee processing wastes. *Trop. Sci.,* **23**, 177-196.

Bernabé-González, T., M. S. Domínguez & S. A. Bautista, (1991), Cultivo de *Pleurotus floridanus* Singer, sobre fibra de coco y mezclada con pulpa de café. Paper presented at 4th Mexican Congress of Mycology, October 14-18, Tlaxcala, Mexico.

Braham, J. & R. Bressani, (1979), *Pulpa de café, composición, tecnología y utilización*, CIID, Bogota, Colombia.

Calvo-Bado, L. A., J. E. Sánchez-Vázquez & G. Huerta-Palacios, (1996), Cultivo de *Auricularia fuscosuccinea* (Mont.)Farlow sobre sustratos agrícolas en el Soconusco, Chiapas, México. *Micol. Neotrop. Apl.*, **9**, 95-106.

Chang, S. T. (1996), Mushroom research and development - equality and mutual benefit. In - *Mushroom Biology and Mushroom Products*, D. J. Royse (ed.), Pennsylvania State University, University Park, pp. 1-10.

Chang, S. T. (1999), Global impact of edible and medicinal mushrooms on human welfare in the 21st century: nongreen revolution. *International Journal of Medicinal Mushrooms*, **1**, 1-7.

Chang, S. T. & P. G. Miles, (1989), *Edible Mushrooms and their Cultivation*, CRC Press, Boca Raton, U.S.A.

Chang, S. T. & P. G. Miles, (1991), Recent trends in world production of cultivated edible mushrooms. *Mushroom Journal*, **504**, 15-18.

Duke, J. A. & A. A. Atchley, (1986), *CRC Handbook of Proximate Analysis Tables of Higher Plants*, CRC Press, Boca Raton, U.S.A.

Flegg, P. B. (1991), Used compost: a resource or liability? *Mushroom Journal*, **504**, 27.

Flegg, P. B., D. M. Spencer & D. A. Wood, (1985), *The Biology and Technology of the Cultivated Mushroom*, John Wiley & Sons, Chichester, England.

Gaime-Perraud, I., S. Roussos & D. Martínez-Carrera, (1993), Natural microorganisms of the fresh coffee pulp. *Micol. Neotrop. Apl*., **6**, 95-103.

Grabbe, K. (1990), Upgrading of lignocellulosics from agricultural and industrial production processes into food, feed and compost-based products. In- *Advances in Biological Treatment of Lignocellulosic Materials*, M. P. Coughlan & M. T. Amaral Collaço (ed.), Elsevier Applied Science Publishers, Barking, pp. 331-342.

Maher, M. J. (1991), Spent mushroom compost (SMC) as a nutrient source in peat based potting substrates. *Mushroom Science*, **13**, 645-650.

Martínez-Carrera, D. (1984), Cultivo de *Pleurotus ostreatus* sobre desechos agrícolas. I. Obtención y caracterización de cepas nativas en diferentes medios de cultivo sólido en el laboratorio. *Biotica*, **9**, 243-248.

Martínez-Carrera, D. (1987), Design of a mushroom farm for growing *Pleurotus* on coffee pulp. *Mushroom Journal for the Tropics*, **7**, 13-23.

Martínez-Carrera, D. (1989a), Simple technology to cultivate *Pleurotus* on coffee pulp in the tropics. *Mushroom Science*, **12**, 169-178.

Martínez-Carrera, D. (1989b), Past and future of edible mushroom cultivation in tropical America. *Mushroom Science*, **12**, 795-805.

Martínez-Carrera, D. (1998), Oyster mushrooms. *McGraw-Hill Yearbook of Science & Technology 1999*. McGraw-Hill, Inc., New York. Pp. 242-245. ISBN 0-07-052625-7 [http://books.mcgraw-hill.com].

Martínez-Carrera, D. (2000), Mushroom biotechnology in tropical America. *International Journal of Mushroom Sciences*, **3**, 9-20.

Martínez-Carrera, D. (2002), Mushroom. *McGraw-Hill Encyclopedia of Science and Technology, 9th Edition*. McGraw-Hill, Inc., New York. 4 pp. ISBN 0-07-913665-6 [http://books.mcgraw-hill.com; http://www.mhest.com].

Martínez-Carrera, D. & A. Larqué-Saavedra, (1990), Biotecnología en la producción de hongos comestibles. *Ciencia y Desarrollo*, **95**, 53-64.

Martínez-Carrera, D. & A. López, (1982), Obtención, caracterización y comportamiento de cepas de *Pleurotus ostreatus* en cultivo de laboratorio, Paper presented at 1st. Mexican Congress of Mycology, October 26-30, Xalapa, Veracruz, Mexico.

Martínez-Carrera, D., A. Aguilar, W. Martínez, P. Morales, M. Sobal, M. Bonilla & A. Larqué-Saavedra, (1998), A sustainable model for rural production of edible mushrooms in Mexico. *Micol. Neotrop. Apl*., **11**, 77-96.

Martínez-Carrera, D., A. Larqué-Saavedra, P. Morales, M. Sobal, W. Martínez & A. Aguilar, (1993), Los hongos comestibles en México, biotecnología de su reproducción. *Ciencia y Desarrollo*, **108**, 41-49.

Martínez-Carrera, D., C. Soto & G. Guzmán, (1985a), Cultivo de *Pleurotus ostreatus* en pulpa de café con paja como substrato. *Rev. Mex. Mic.*, **1**, 101-108.

Martínez-Carrera, D., F. Vergara, S. Juarez, A. Aguilar, M. Sobal, W. Martínez & A. Larqué-Saavedra, (1996a), Simple technology for canning cultivated edible mushrooms in rural conditions in Mexico. *Micol. Neotrop. Apl.*, **9**, 15-27.

Martínez-Carrera, D., G. Guzmán & C. Soto, (1985b), The effect of fermentation of coffee pulp in the cultivation of *Pleurotus ostreatus* in Mexico. *Mushroom Newsletter for the Tropics*, **6**, 21-28.

Martínez-Carrera, D., M. Quirarte, C. Soto, D. Salmones & G. Guzmán, (1984), Perspectivas sobre el cultivo de hongos comestibles en residuos agro-industriales en México. *Bol. Soc. Mex. Mic.*, **19**, 207-219.

Martínez-Carrera, D., M. Sobal & P. Morales, (1988), El efecto de la cafeína sobre el crecimiento e intracruzamiento de *Pleurotus ostreatus* en el laboratorio. *Rev. Mex. Mic.*, **4**, 131-135.

Martínez-Carrera, D., M. Sobal, P. Morales & A. Larqué-Saavedra, (1992a), Prospects of edible mushroom cultivation in developing countries. *Food Laboratory News*, **8**(3), 21-33.

Martínez-Carrera, D., M. Sobal, P. Morales, W. Martínez-Sánchez, A. Aguilar & A. Larqué-Saavedra, (1995), Edible mushroom cultivation and sustainable agriculture in Mexico. *The African Journal of Mycology and Biotechnology*, **3**, 13-18.

Martínez-Carrera, D., P. Morales & M. Sobal, (1990), Cultivo de *Pleurotus ostreatus* sobre bagazo de caña enriquecido con pulpa de café o paja de cebada. *Micol. Neotrop. Apl*., **3**, 49-52.

Martínez-Carrera, D., P. Morales, M. Sobal & A. Larqué-Saavedra, (1992b), Reconversión en la industria de los hongos? *TecnoIndustria*, **7**, 52-59.

Martínez-Carrera, D., P. Morales, M. Sobal, S. T. Chang & A. Larqué-Saavedra, (1991a), Edible mushroom cultivation for rural development in tropical America. *Mushroom Science*, **13**, 805-811.

Martínez-Carrera, D., P. Morales, W. Martínez, M. Sobal & A. Aguilar, (1996b), Large-scale drying of coffee pulp and its potential for mushroom cultivation in Mexico. *Micol. Neotrop. Apl.*, **9**, 43-52.

Martínez-Carrera, D., R. Leben, P. Morales, M. Sobal & A. Larqué-Saavedra, (1991b), Historia del cultivo comercial de los hongos comestibles en México. *Ciencia y Desarrollo*, **96**, 33-43.

Pimentel, D., J. Houser, E. Preiss, O. White, H. Fang, L. Mesnick, T. Barsky, S. Tariche, J. Schreck & S. Alpert, (1997), Water resources: agriculture, the environment, and society. *Bioscience*, **47**, 97-106.

Roussos, S., I. Gaime-Perraud, M. Raimbault, G. Viniegra, M. R. Trejo, A. Aquiahuatl & M. Gutiérrez, (1991), Avances en la valorización biotecnológica de los subproductos del café. Paper presented at 2nd. Internat. Seminar on Biotechnology of Coffee Industry, April 12-15, Manizales, Colombia.

Soccol, C. R., S. Roussos & T. Sera, (1999), Abstracts III International Seminar on Biotechnology in the Coffee Agroindustry, May 24-28, Londrina, Brazil.

Soto, C., D. Martínez-Carrera, P. Morales & M. Sobal, (1987), La pulpa de café secada al sol, como una forma de almacenamiento para el cultivo de *Pleurotus ostreatus*. *Rev. Mex. Mic.*, **3**, 133-136.

Tschierpe, H. J. & K. Hartmann, (1977), A comparison of different growing methods. *Mushroom Journal*, **60**, 404-416.

van Griensven, L. J. L. D. (1988), *The Cultivation of Mushrooms*, Darlington Mushroom Laboratories, Rustington, England.

Wasser, S. P. & A. L. Weis, (1999), Medicinal properties of substances occurring in higher basidiomycetes mushrooms: current perspectives (review). *International Journal of Medicinal Mushrooms*, **1**, 31-62.

Watt, B. K. & A. L. Merrill, (1975), *Composition of Foods*, Agriculture handbook no. 8, United States Department of Agriculture, Washington, D. C., U.S.A.

Wood, D. A. (1985), Useful biodegradation of lignocellulose. In- *Plant Products and the New Technology*, K. W. Fuller & J. R. Gallon (ed.), Clarendon, Oxford, pp. 295-309.

**Table 1**. Edible fungi which can be cultivated on coffee pulp, either as a sole substrate or mixed with other organic materials (Martínez-Carrera, 1987, 1989a-b; Martínez-Carrera *et al*., 1985a-b, 1990, 1996b; Bernabé-González *et al*., 1991; Calvo-Bado *et al*., 1996).

| Species | Substrate | Dry weight (g) | Average yield (g) | Biological efficiency (%)[1] |
|---|---|---|---|---|
| *Auricularia fuscosuccinea* | *Inga* sawdust + coffee pulp[2] | 159.3 | 59.2 | 37.1 |
| | Corn cobs + coffee pulp + *Leucaena*[3] | - | - | 20.8 |
| *Lentinula edodes* | *Quercus* sawdust + wheat bran + coffee pulp[4] | 232.7 | 50.9 | 21.8 |
| *Pleurotus* sp. cfr. Florida | Coffee pulp[5] | 999 | 1,756.5 | 175.8 |
| | Coffee pulp + coconut fibre[6] | 500 | 447 | 89.4 |
| *P. ostreatus* | Coffee pulp[5] | 999 | 1,598 | 159.9 |
| | Coffee pulp + sugar cane bagasse[7] | 1,350 | 1,309 | 96.9 |
| | Coffee pulp + barley straw[6] | 1,611 | 1,607 | 99.7 |
| *P. sajor-caju* | Coffee pulp[5] | 999 | 1,280 | 128.1 |
| *P. opuntiae* | Coffee pulp[5] | 999 | 1,437 | 143.8 |
| *P. salmoneo-stramineus* | Coffee pulp[5] | 999 | 1,549 | 155 |

[1] Yield of fruit bodies (fresh weight) as a percentage of the dry weight of substrate at spawning (Tschierpe & Hartmann, 1977).

[2] Sterile substrate; proportion 1:1 on a dry weight basis.
[3] Sterile substrate; proportion 94:3:3 on a dry weight basis.
[4] Sterile substrate; proportion 1:1:1 on a dry weight basis.
[5] Pasteurized.
[6] Pasteurized; proportion 1:1 on a dry weight basis.
[7] Pasteurized; proportion 2:1 on a dry weight basis.

**Table 2**. Effect of aerobic fermentation of coffee pulp on the mushroom yield of *Pleurotus ostreatus* (Martínez-Carrera *et al*., 1985b).

| Treatment | pH | Dry weight substrate (kg) | T[1] | Average yield (g) | Biological efficiency (%) |
|---|---|---|---|---|---|
| Fresh | 6.0 | 1.161 | 34 | 1,316 | 113.3 |
| 5 days fermentation | 6.0 | 0.999 | 23 | 1,320 | 132.1 |
| 10 days fermentation | 7.0 | 0.954 | 36 | 1,135 | 118.9 |

[1] Average time after spawning to produce the first flush (days).

**Table 3**. Caffeine content of coffee pulp used as a substrate for the cultivation of *Pleurotus* mushrooms (Martínez-Carrera *et al*., 1985b).

| Coffee pulp treatment | Caffeine content (%) | | |
|---|---|---|---|
| | Before pasteurization | After pasteurization[1] | After mushroom cultivation[2] |
| Fresh | 0.99 | 0.25 | 0.20 |
| 5 days fermentation | 0.52 | 0.20 | 0.14 |
| 10 days fermentation | 0.45 | 0.22 | 0.20 |

[1] Immersion in hot water at 70°C for 15 min.
[2] After mycelial growth, fruiting, and harvesting four flushes.

**Table 4**. Mushroom yields of *Pleurotus ostreatus* cultivated on coffee pulp dried by direct exposure to the sun, stored for different periods of time, and pasteurized (Soto *et al*., 1987).

| Period of storage of the coffee pulp (months) | Dry weight substrate (kg) | Average yield (g) | Biological efficiency (%)[1] |
|---|---|---|---|
| Control (fermented for 5 days) | 0.888 | 1,418 | 159.6 |
| 1 | 0.888 | 1,267 | 142.6 |
| 2 | 0.888 | 1,298 | 146.1 |
| 7 | 0.888 | 1,265 | 142.4 |
| 12 | 0.888 | 1,346 | 152.7 |
| 24 | 0.888 | 1,290 | 145.2 |

[1] Yield of fruit bodies (fresh weight) as a percentage of the dry weight of substrate at spawning (Tschierpe & Hartmann, 1977).

**Table 5**. Proximate chemical analysis of coffee pulp dried artificially (Martínez-Carrera *et al*., 1996b).

| Component/characteristic | Coffee pulp | |
|---|---|---|
| | Fresh | Dry |
| pH (1:10) | 4.4 | 5.6 |
| Carbon / nitrogen | 67.5 | 50.6 |
| Organic matter | 92.9% | 91.4% |
| Nitrogen | 0.80% | 1.05% |
| Phosphorus | 0.11% | 0.13% |
| Potassium | 3.51% | 3.99% |
| Calcium | 0.53% | 0.63% |
| Magnesium | 0.12% | 0.15% |

**Table 6**. Proximate chemical analysis of spent coffee pulp after the cultivation of *Pleurotus ostreatus* (Martínez-Carrera, 1989a).

| Component/characteristic | % |
|---|---|
| Moisture | 81.8 |
| Ash | 15.2 |
| Crude fat | 1.8 |
| Carbohydrates | 29.9 |
| Crude protein (N x 6.25) | 21.5 |
| Crude fibre | 31.4 |
| Tannin (qualitative analysis) | Negative |

**Table 7**. Costs (USD) of production and operation in a rural commercial farm from Cuetzalan, Puebla, Mexico (Martínez-Carrera *et al*., 1998).

| Years | Salaries | Raw materials and energy | Administration expenses | Travelling expenses | Maintenance | Marketing |
|---|---|---|---|---|---|---|
| 1992-1997 | 17,845.09 | 12,418.45 | 928.78 | 2,042.04 | 2,505.22 | 1,197.01 |
| (%) | (48.3) | (33.6) | (2.5) | (5.5) | (6.8) | (3.3) |

**Table 8**. Financial analysis of the commercial mushroom production in a rural farm from Cuetzalan, Puebla, Mexico (Martínez-Carrera *et al*., 1998).

| Years | Production costs ($) | Gross incomes ($) | Profits ($) | | | Cost-benefit ratio |
|---|---|---|---|---|---|---|
| | | | Fresh oyster mushrooms | Spawn | Total | |
| 1992-1997 | 36,936.59 | 40,576.57 | 2,536.60 | 1,103.36 | 3,639.96 | 1.10[1] |

[1] Average data.

**Table 9**. Estimated amount of water required for producing 1 kg of fresh oyster mushrooms using rustic technologies, in comparison with that for other food and forage crops (Martínez-Carrera *et al*., 1998).

| Product | Litres of water/kg | Protein content[a] (g) | Litres of water per gram of protein |
|---|---|---|---|
| Oyster mushrooms (*Pleurotus*) | 28 | 2.7 | 1.0 |
| Potatoes | 500[b] | 2.1 | 23.8 |
| Wheat | 900[b] | 14.0 | 6.4 |
| Alfalfa | 900[b] | 6.0 | 15 |
| Sorghum | 1,110[b] | 11.0 | 10.0 |
| Corn | 1,400[b] | 3.5 | 40.0 |
| Rice | 1,912[b] | 6.7 | 28.5 |
| Soybeans | 2,000[b] | 34.1 | 5.8 |
| Broiler chicken | 3,500[b] | 23.8 | 14.7 |
| Beef | 100,000[b] | 19.4 | 515.4 |

[a] Composition in 100 g, edible portion (fresh weight) [Watt & Merrill, 1975; Duke & Atchley, 1986; Chang & Miles, 1989].
[b] Data according to Pimentel *et al*. (1997).

**Table 10**. Environmental, economic, and social indicators which contributed to understand the sustainability of the model for rural production of edible mushrooms using rustic technologies in the coffee growing region of Cuetzalan, Puebla, Mexico, during the period 1992-1997 (Martínez-Carrera *et al*., 1998).

| Category | Indicator | Critical value | Factor(s) evaluated |
|---|---|---|---|
| Environmental | Biological efficiency | > 32% | Spawn, yields, substrates |
| | Degradation rate | > 31% | Spent substrates, potential organic fertilizer [a] |
| | Contamination rate | < 20% | Raw materials, growing systems and technology, spawn, environmental conditions, hygiene, labour skills |
| | Energy-use efficiency | < 12% | Energy consumption [b] |
| | Water-use efficiency | > 28 L/kg | Water consumption to produce mushrooms |
| | Temperature | 15° C | Minimum temperature [c] |
| | | 33°C | Maximum temperature [c] |
| | Relative humidity | > 70% | Environmental moisture |
| Economic | Cost-benefit ratio | > 1.0 | Gross incomes, production costs, profits |
| Social | Mushroom consumption | > 0.914 kg | *Per capita* [d] |
| | | > 4.100 kg | per household [d] |
| | Labour efficiency | < 3 | Number of workers in the farm [e] |
| | Market | qe | Potential increase in mushroom production within the farm [f] |

qe= Qualitative estimations are usually available, as market trends depend on social, economic, and political circumstances. The market can be local, national or international. National production, imports, exports, real and potential domestic demand are to be considered.

[a] Variations are not significant on a large scale. Data expressed on a dry weight basis.

[b] Proportion as a percentage from total production cost.

[c] Temperatures may be higher or lower, depending on strain tolerance.

[d] Minimum mushroom consumption per year required to maintain the mushroom farm.

[e] Each worker should produce at least 1,689 kg per year.

[f] If enough financial support is available.

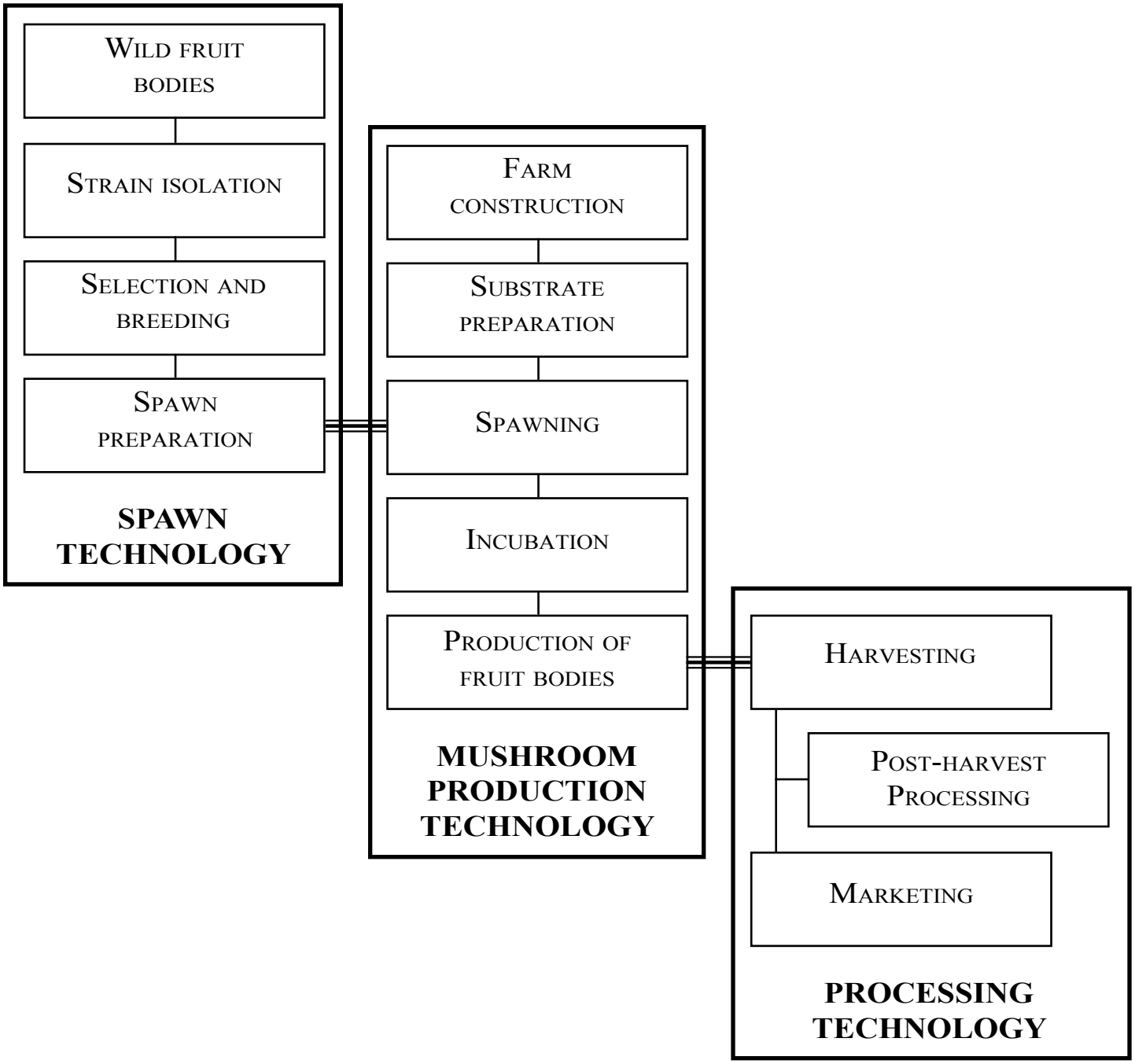


**Fig. 1**. Fundamental principles of mushroom biotechnology.

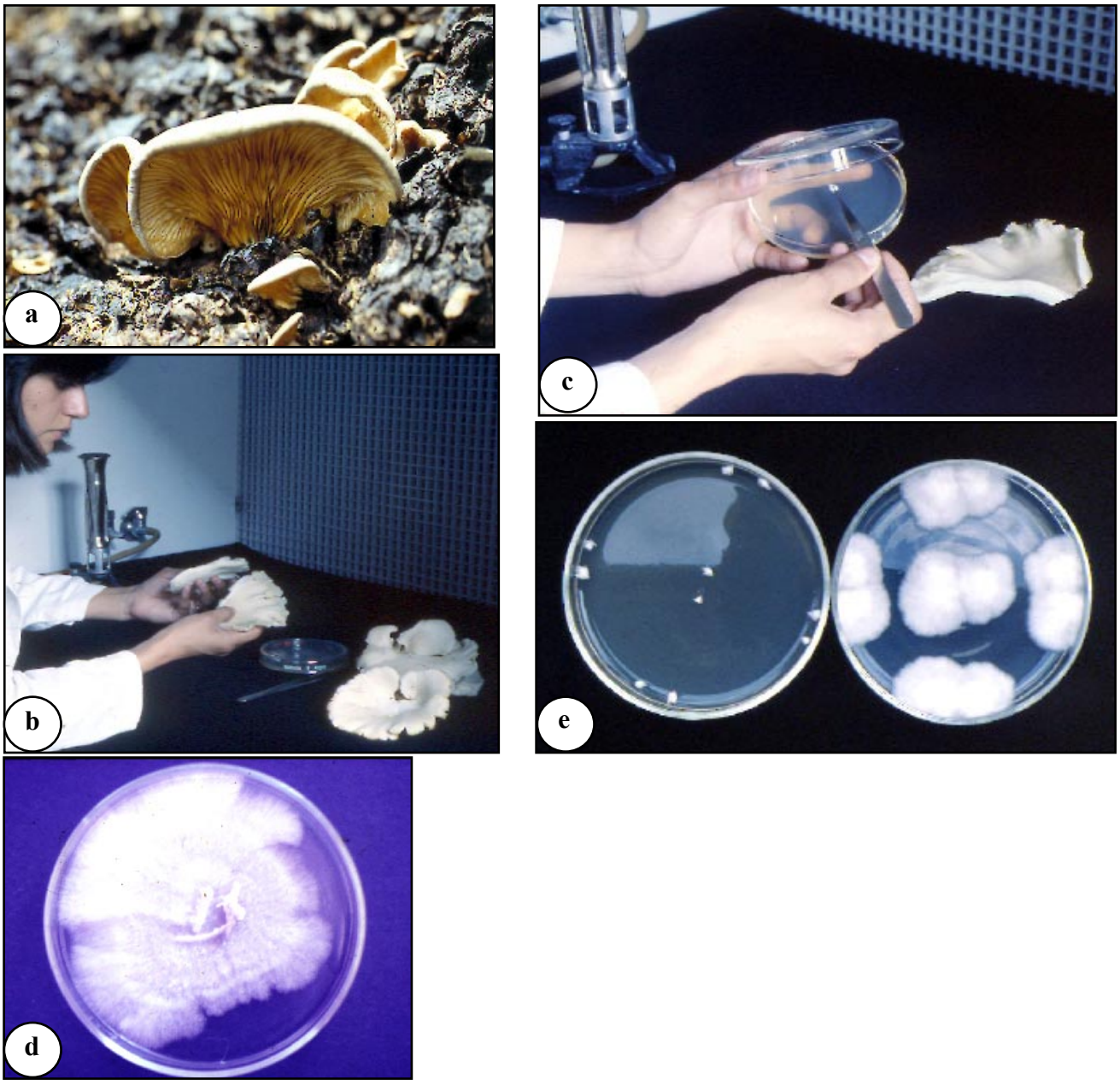


**Fig. 2a-e**. Several aspects of spawn technology. a: wild fruit bodies of *Pleurotus* growing on coffee pulp. b-c: isolation of strains by tissue culture from wild fruit bodies, under aseptic conditions in the laboratory. d: mycelial growth developed from tissue culture on agar plate. e: interstock matings between compatible strains selected for mushroom breeding.


**Fig. 3a-d**. Preparation of spawn of cultivated edible mushrooms. a: washing and sterilization of wheat kernels. b: inoculation under aseptic conditions. c: mycelial development on sterilized wheat kernels. d: incubation room for small-scale production of spawn.

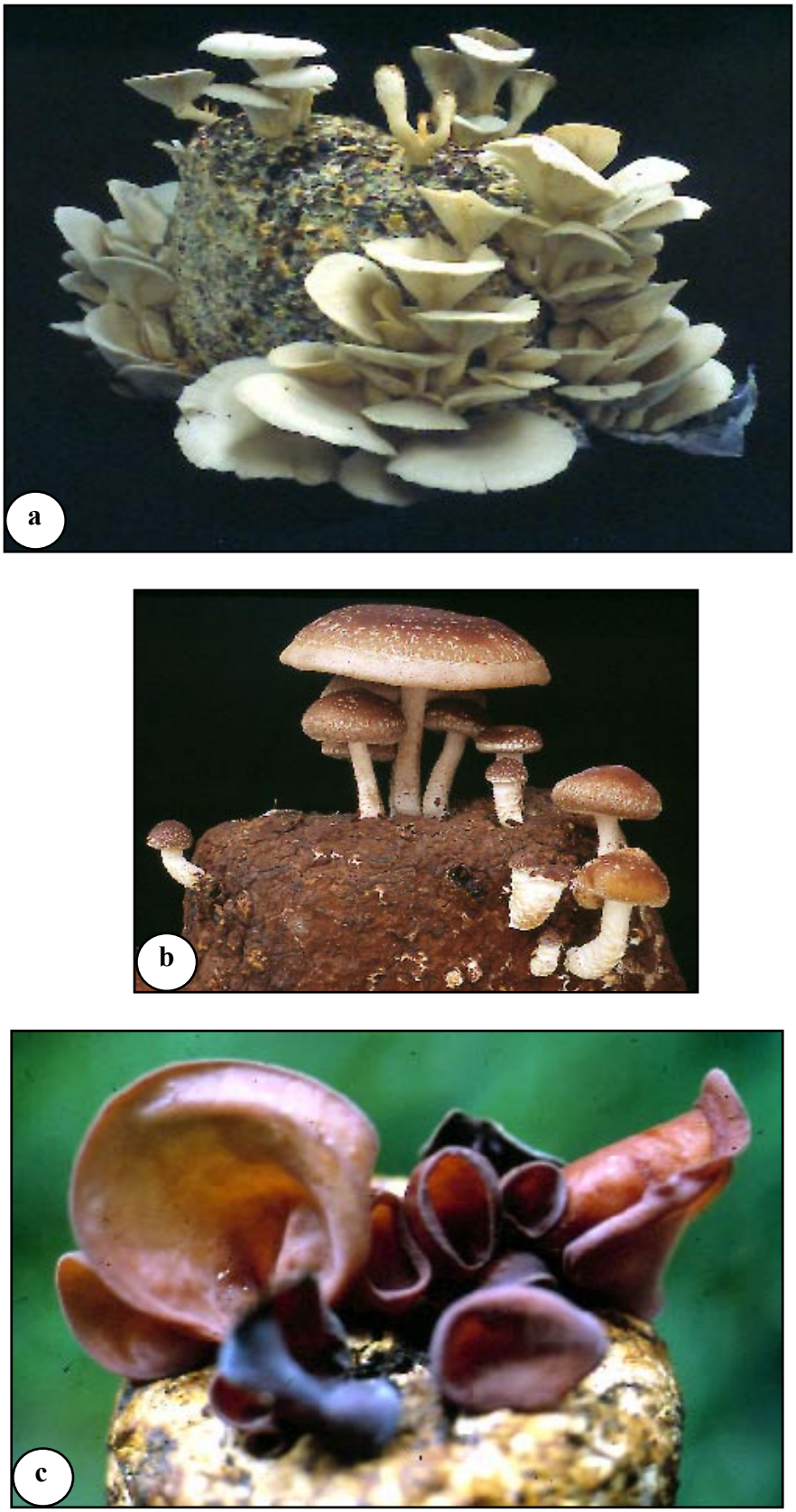


**Fig. 4a-c**. Edible mushrooms which can be cultivated on coffee pulp, either as a sole substrate or supplemented with other organic materials. a: *Pleurotus*. b: *Lentinula*. c: *Auricularia*.

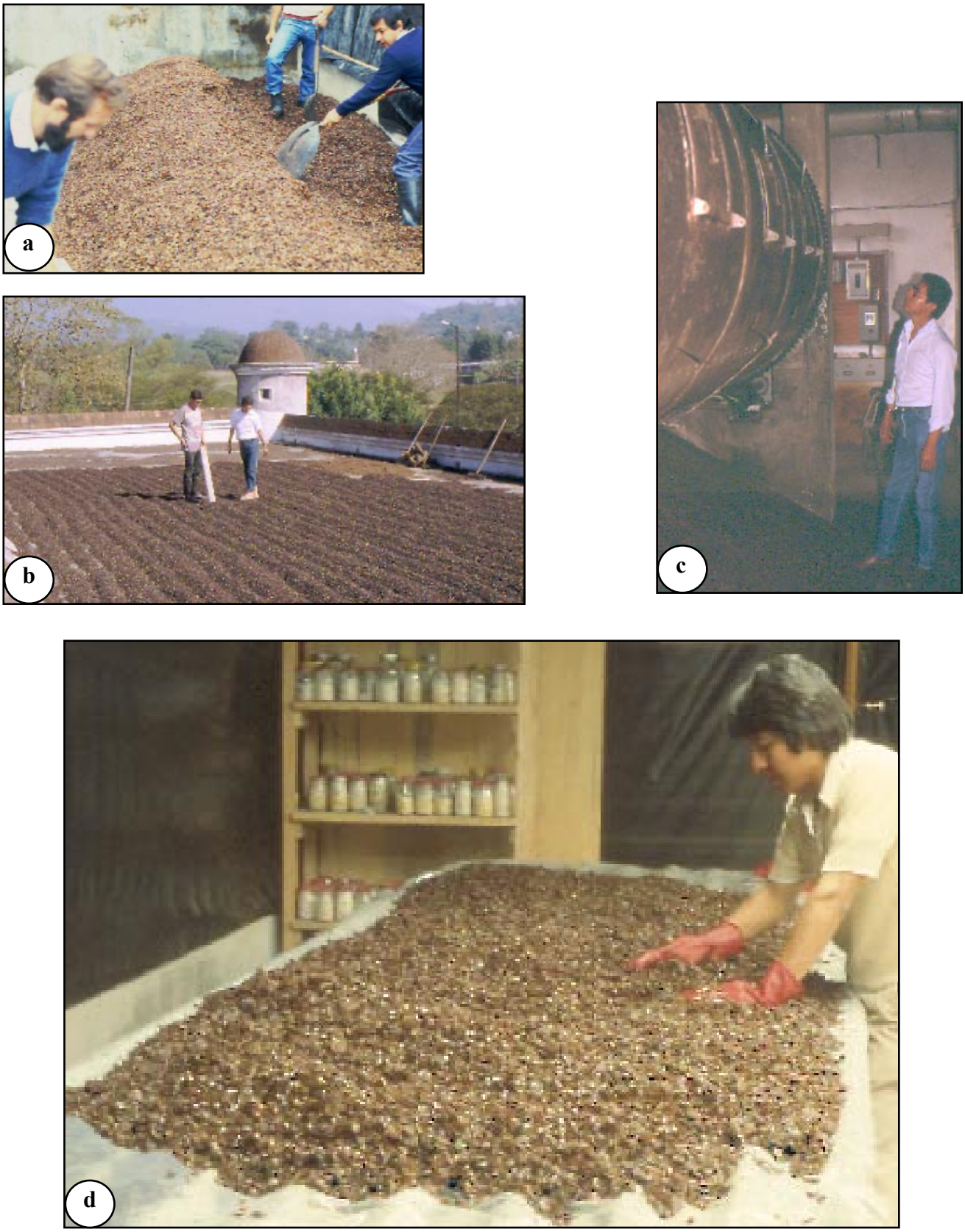


**Fig. 5a-d**. Coffee pulp preparation for mushroom cultivation. a: aerobic fermentation. b: solar drying of fresh coffee pulp. c: artificial drying of fresh coffee pulp loaded in a commercial coffee dryer. d: pasteurized coffee pulp ready for spawning.

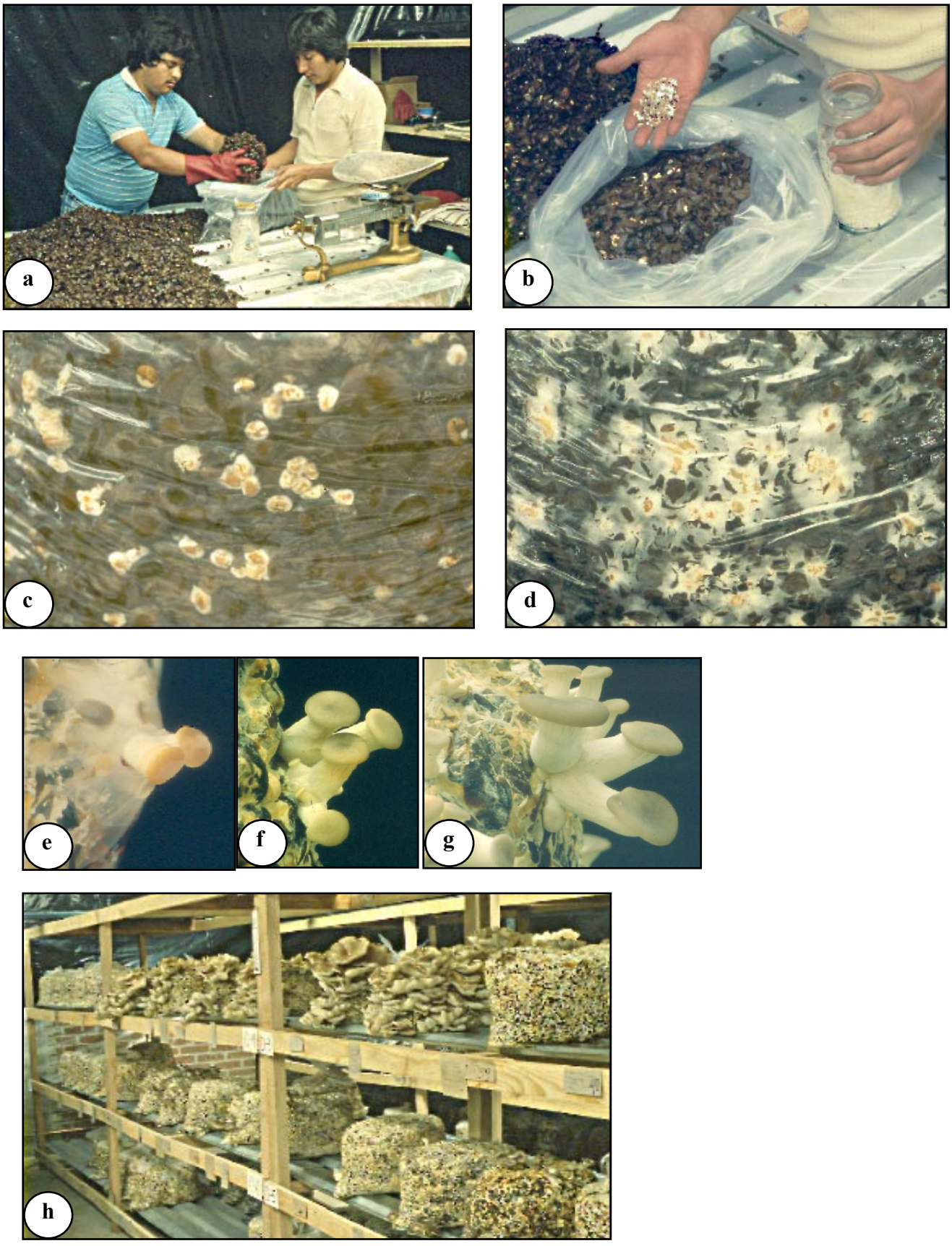


**Fig. 6a-h**. Coffee pulp as a substrate for *Pleurotus* production. a: introduction in containers (plastic bags). b: spawning. c-d: mycelial growth on coffee pulp after spawning. e-g: primordia and fruit-body development. h: commercial production on coffee pulp.


**Fig. 7a-d**. Rural production of edible mushrooms (*Pleurotus*) in Cuetzalan, Puebla, Mexico. a: commercial production at the central farm. b: domestic cultivation in a rural community. c: preparation of fresh mushrooms for the local market. d: mushroom canning using Mexican recipes.



**Fig. 8a-b**. a: spent coffee pulp after mushroom (*Pleurotus*) cultivation. b: organic fertilizer produced by vermi-composting of spent coffee pulp mixed with other organic materials.