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CURRENT DEVELOPMENT OF MUSHROOM BIOTECHNOLOGY IN LATIN AMERICA

D. MARTÍNEZ-CARRERA

College of Postgraduates in Agricultural Sciences (CP), *Campus* Puebla, Mushroom Biotechnology, Apartado Postal 701, Puebla 72001, Puebla, Mexico. Fax: (52) 222-2852162. E-mail: dcarrera@colpos.colpos.mx

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ABSTRACT

There is a paucity of information about the commercial production of edible mushrooms in Latin America. During the period 1995-2001, estimated production increased 32% in this region, from 49,975 to 65,951 tonnes/year. Its total economic value reached more than 167 million dollars per year, and about 34 thousand people work for this activity. Leading countries are Mexico (58.6%), Chile (17.6%), and Brazil (10.6%) accounting for 86.8% of total mushroom production. The mushroom consumption *per capita* in Latin America is low (*ca*. 125 g/year). The rural household system model (RHS) has been developed for assessing the significance and fundamental trends of rural mushroom cultivation. Despite this remarkable development in recent years and the Latin American mega-biodiversity, the recovery and conservation of native germplasm from edible mushrooms have only been undertaken by several research collections. Future challenges of research and development are outlined considering the main mushroom activities being carried out in the region. Those countries, in which mushroom cultivation is not yet well established, will find difficulty to cope with the new competitive circumstances generated by globalisation.

Key words: Mushroom biotechnology, commercial production, culture collections, *Agaricus*, *Pleurotus*, *Lentinula*, Latin America.

INTRODUCTION

A thorough knowledge of the context is fundamental to develop strategies for promoting any human activity. In general, there is a paucity of information about the commercial production of edible mushrooms in Latin America. Historical and basic overviews are available for individual countries, such as Argentina [41], Colombia [18], Guatemala [9, 10], and Mexico [28]; while three general reviews for the whole region have been published by Martínez-Carrera [16, 17] and Lahmann and Rinker [15]. It has been shown that mushroom cultivation was introduced to Latin America till 1933 from Europe [28]. Such early efforts in central Mexico ended up in the establishment of the company "Hongos de Mexico" in 1949, nowadays the largest farm in Latin America producing around 55 tonnes of *Agaricus* mushrooms per day. This was followed by other Latin American countries, such as Argentina, Colombia, Brazil, Chile, Guatemala, Peru, Ecuador, Venezuela, Costa Rica, and more recently Bolivia [17].

CURRENT DEVELOPMENT

Annual production has increased steadily in Latin America since 1945 (**Table 1**). During the period 1995-2001, estimated commercial mushroom production in this region increased 32%, from 49,975 to 65,951 tonnes/year (equivalent to *ca*. 2,627 tonnes of protein). Thus mushroom production increased at a rate of about 5% per year. Despite this remarkable development (**Fig. 1**), Latin America only produces about 1.3% from the total world commercial production of cultivated mushrooms [8, 13], which has been estimated to be in excess of 4,909,300 tonnes per year (fresh weight) . Most production is commercialized in the fresh market, and a small proportion is processed for further distribution. Many countries have high level of imports to satisfy the local demand of fresh and processed mushrooms.

Leading countries are Mexico (58.6%), Chile (17.6%), and Brazil (10.6%) accounting for 86.8% of total mushroom production. Mushroom cultivation brings about social, economic, and ecological benefits to Latin America. It has been estimated that there is still a low mushroom consumption *per capita* of about 125 g per year. The total economic value reaches more than 167 million dollars per year, and about 34 thousand people work, directly or indirectly, for this activity. Around 656,796 tonnes of by-products from agriculture and forestry are recycled every year as substrates for mushroom cultivation.

Agaricus, the common cultivated mushroom; and *Pleurotus,* the oyster mushroom, are the most important cultivated mushrooms in an estimated proportion of about 95% and 5%, respectively. *Lentinula,* the *shiitake* mushroom, is beginning to be commercially grown in Colombia, Brazil, Guatemala, Argentina, and Mexico [17]. Although facing serious problems of basic knowledge, working capital, technical assistance, strain or spawn availability, and marketing strategies, Latin American mushroom growers have succeeded in: 1) Adapting European, North American and/or Asian technologies to the local conditions of each country; 2) Promoting consumption and marketing of fresh and processed mushrooms; and 3) Training mushroom farm workers [17].

MUSHROOM SPAWN

In the beginning of Latin American mushroom industry, the spawn used was normally

Table 1. Commercial production of edible mushrooms in different Latin American countries [15, 17, 28].

Country	Tonnes/year (fresh weight)									
	1945	1955	1960	1965	1970	1972	1974	1975	1995	2001
Argentina	-	-	-	-	150	300	600	700	1,200	1,450
Bolivia	-	-	-	-	-	-	-	-	-	60
Brazil	-	-	-	-	150	350	600	700	4,000	7,000
Colombia	-	-	-	-	100	150	160	180	3,200	3,520
Costa Rica	-	-	-	-	50	500	700	600	100	110
Chile	-	-	-	-	80	100	100	100	10,600	11,660
Ecuador	-	-	-	-	400	460	500	500	320	352
Guatemala	-	-	-	-	10	20	20	10	40	132
Mexico	5	100	200	400	1,150	1,700	2,220	2,430	27,825	38,708
Peru	-	-	-	-	60	70	100	100	300	330
Santo Domingo	-	-	-	-	-	200	1,000	900	990	1,089
Venezuela	-	-	-	-	50	50	100	80	1,400	1,540

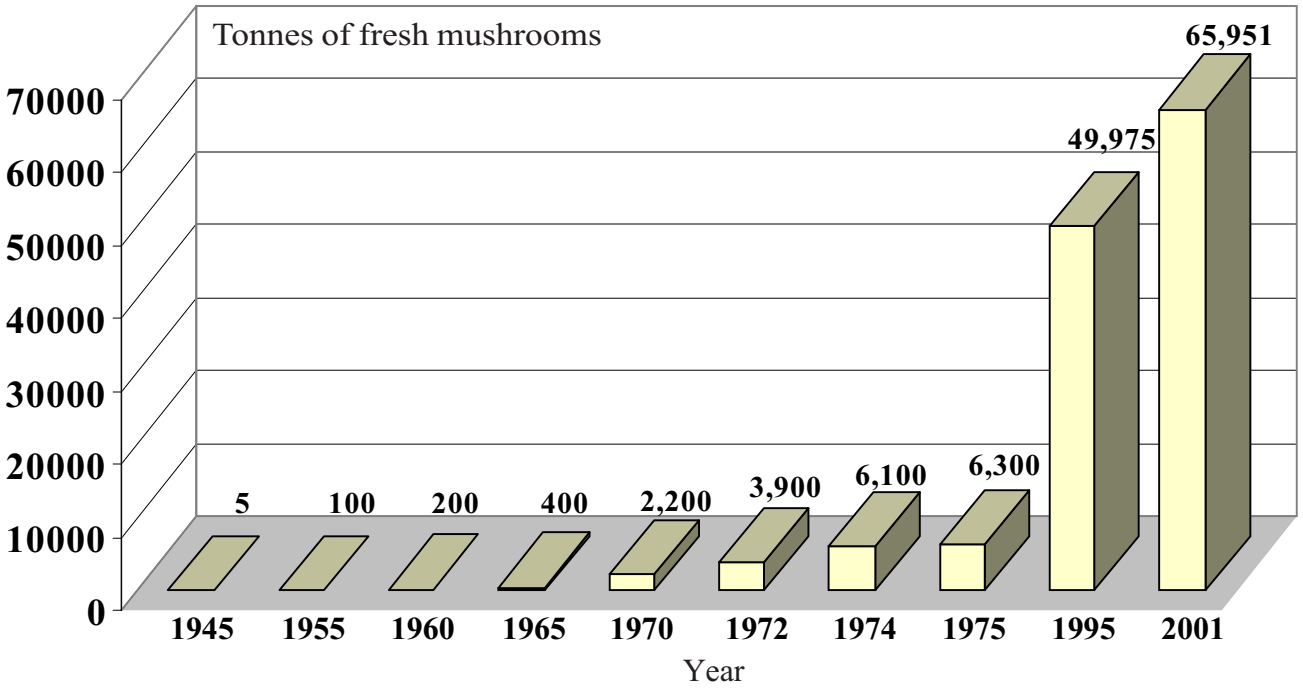

Fig. 1. Development of commercial mushroom production in Latin America during the period 1945-2001 [15, 17, 28].

imported from the U.S.A. and Europe. It was during the period from the 1950's to the 1990's, when several laboratories for spawn production were established within mushroom farms. This was followed by the establishment of independent spawn makers on small scale, as well as distribution centres from international companies (*e.g.* Amycel, Sylvan). At present, most strains cultivated commercially are introduced from other regions, such as North America, Europe, or South Asia. Despite the development of mushroom cultivation, countries in Latin America are just starting to appraise their mega-biodiversity [14]. The recovery and conservation of native germplasm from edible mushrooms have been undertaken since 1961 (**Table 2**), by several research collec-

Table 2. Strains of edible mushrooms, including native germplasm (N), maintained by several research collections in different countries from Latin America.

Country	Year founded	Institution	Number of strains	Genera
Argentina	1961	University of Buenos Aires, Faculty of Natural and Exact Sciences	195	*Agaricus*, *Agrocybe*, *Coriolus*, *Ganoderma*, *Hohenbuehelia*, *Laetiporus*, *Lentinula*, *Lentinus*, *Pleurotus*
	1998	INTECH, Institute of Biotechnological Research, Chascomús	200	*Agaricus*, *Agrocybe*, *Pleurotus*
Brazil	1992	Institute of Botany, Sao Paulo	28 (N)	*Agaricus*, *Pleurotus*, *Lentinula*
	1992	Federal University of Parana, Department of Chemical Engineering, Curitiba	28	*Agaricus*, *Flammulina*, *Lentinula*, *Pleurotus*
Mexico	1982	UNAM, Faculty of Chemistry, Mexico, D.F.	50	*Agaricus*, *Lentinula*, *Pleurotus*, *Volvariella*
	1989	College of Postgraduates, *Campus* Puebla,	100 (N)	*Agaricus*, *Armillariella*, *Auricularia*, *Calvatia*, *Ganoderma*, *Laetiporus*, *Lentinula*, *Pleurotus*, *Stropharia*
	1989	Institute of Ecology, Xalapa	180 (N)	*Agaricus*, *Auricularia*, *Laetiporus*, *Lentinula*, *Neolentinus*, *Pleurotus*, *Volvariella*
	1995	ECOSUR, Tapachula	97 (N)	*Auricularia*, *Ganoderma*, *Pleurotus*
Peru	1990	University of Peru Cayetano Heredia, Faculty of Sciences and Philosophy	29 (N)	*Auricularia*, *Ganoderma*, *Lentinula*, *Pleurotus*

tions from Argentina, Brazil, Mexico [24], and Peru. These collections only reported 907 strains from the genera *Agaricus*, *Agrocybe*, *Armillariella*, *Auricularia*, *Calvatia*, *Coriolus*, *Flammulina*, *Ganoderma*, *Hohenbuehelia*, *Laetiporus*, *Lentinula*, *Lentinus*, *Neolentinus*, *Pleurotus*, *Stropharia*, and *Volvariella*. This is certainly a small number of strains in comparison with the size of the region.

Most strains are maintained by low-cost conventional methods (repeated transfers, continuous growth at room temperature, reduced metabolism at low temperature), and only a few strains have been deposited with service culture collections for long-term preservation. There is also a lack of expertise, institutional commitment, and funds which represent a high risk of germplasm loss. It is therefore important that Latin American collections evolve towards a regional network of mushroom research collections, and later towards the establishment of a biological resource center (BRC). According to international standards, main services of this BRC would include : 1) Native germplasm preservation and maintenance; 2) Suitable storage, identification, characterisation (classical, molecular), screening, and/or purification of strains used commercially; 3) The distribution or exchange of living cultures; 4) Patent deposit facilities; 5) Preservation of DNA related parts from edible mushrooms; 6) Access to associated databases arising from developments in molecular biology; and 7) Organization of meetings, courses, and programmes for biodiversity prospecting and protection.

MUSHROOM PRODUCTION

Agaricus

Diverse compost formulations are prepared using regional raw materials. Most formulations are based on straw, regional grasses, corn stubble, sugar cane bagasse, horse or chicken manure, gypsum, and a variety of available supplements. Most farms of different countries make or import machinery for specific parts of the cultivation process. A variety of growing systems are used for *Agaricus* cultivation (**Fig. 2**), such as wooden shelves, trays, plastic bags, and recently Dutch shelves. Black soil, peat, coconut husks, rice hulls, and palm fibre are

Fig. 2. Compost preparation, and cultivation in plastic bags of *Agaricus* mushrooms in Mexico.

used as casing material [17]. Apart from commercial strains of *A. bisporus* (Lange) Imbach, which are cultivated at high altitudes of temperate climate in the region, other species have recently been brought into cultivation. This is the case of a tropical strain from the *A. bitorquis* (Quél.)Sacc. complex, capable of fruiting at 28ºC, and cultivated in Bolivia [39]. Another introduced *Agaricus* strain producing brownish fruit bodies is becoming popular in central Mexico, where it is marketed under the name "portabella" or "portobello".

Pleurotus

Oyster mushrooms began to be cultivated in 1974 [17]. Large-scale substrate preparation involves an outdoor aerobic fermentation for a few days, and then pasteurization in bulk with steam for several hours. Main substrates used are straw, coffee pulp, corn stubble, cotton waste, tequila bagasse, as well as other regional agricultural by-products (**Table 3**). Biological efficiencies vary from 14-159%. Pasteurized substrates are spawned mechanically.

Table 3. Different agricultural by-products which have been used as substrates for *Pleurotus* cultivation in Latin America.

Substrate	BE (%)	Reference
Wheat/barley straw	96.0	Martínez-Carrera, 1989 [16, 19]
Coffee pulp	159.9	
Sugar cane bagasse	14.1	
Sugar cane bagasse + straw	65.0	
Sugar cane bagasse + coffee pulp	99.9	
Cinnamon leaves	81.8	
Lemon grass leaves	113.0	
Pepper leaves	56.7	
Cardamom pulp	113.6	
Cotton waste	56.4	
Subtropical forest dead leaves	35.2	
Tequila bagasse	60.2-64.7	Guzmán-Dávalos *et al*., 1987 [12]
Corn cobs	50.5	Acosta *et al*., 1988 [1]
Coconut fibre	80.6	Bernabé-González *et al.*, 1993 [7]
Broad bean stubble	113.5-118.0	Sobal *et al.*, 1993 [46]
Black kidney bean stubble	99.8-137.6	
Peanut husk	85.4	Bernabé-González and Arzeta-Gómez, 1994 [5]
Maize leaves	144.8	
Sorghum straw	132.3	Bernabé-González and Garzón-Mayo, 1995 [6]
Sugar cane leaves	40.9-89.4	Mata and Gaitán, 1995 [31]
Cocoa shells	40.8-84.5	Bermúdez *et al*., 2001 [4]
Coconut shells	90.0	

BE= Biological efficiency (yield of fresh fruit bodies as a percentage of the dry weight of substrate at spawning).

Oyster mushrooms are cultivated using a variety of systems, such as cylindrical containers, plastic bags in shelves, stacked plastic bags with or without a central support, plastic columns, and plastic bags in wooden shelves (**Fig. 3A**). Most cultivation rooms are simple, without sophisticated controls for temperature or relative humidity.

Main cultivated species are European strains of *Pleurotus ostreatus* (Jacq. ex Fr.)Kumm.; *P. ostreatus* strain "florida"; *P. sajor-caju* (Fr.)Singer; our strain CP-50 of *P. ostreatus* capable of growing under subtropical conditions [37]; and occasionally pink species of *Pleurotus*.

Small-scale cultivation of oyster mushrooms is carried out using rustic pasteurization methods by immersion in hot water. Spawning is normally done by hand. Main cultivation systems are stacked plastic bags, plastic bags laid down on the floor or in wooden shelves. Most growing rooms have normally been adapted from other activities to mushroom cultivation (**Fig. 3B-D**).

This type of cultivation does not require large investments. It may be continuous or seasonal, and it has helped to promote mushroom cultivation in rural areas, following a model of technology transfer developed in central Mexico [20]. The rural production of oyster mushrooms began in 1989, and its development and significance have been assessed through the rural household system model [2, 27]. Main trends show that rural household units or systems (RHSs) integrate mushroom cultivation as an extra-agricultural activity to differing extents, and their production varies from 2.6-156 tonnes per year. Mushroom biotechnology can therefore be adopted and adapted to the RHS needs, keeping a proper balance with other agricultural and extra-agricultural activities. Mushroom cultivation provides incomes, labour opportunities, and food to the RHS [2].

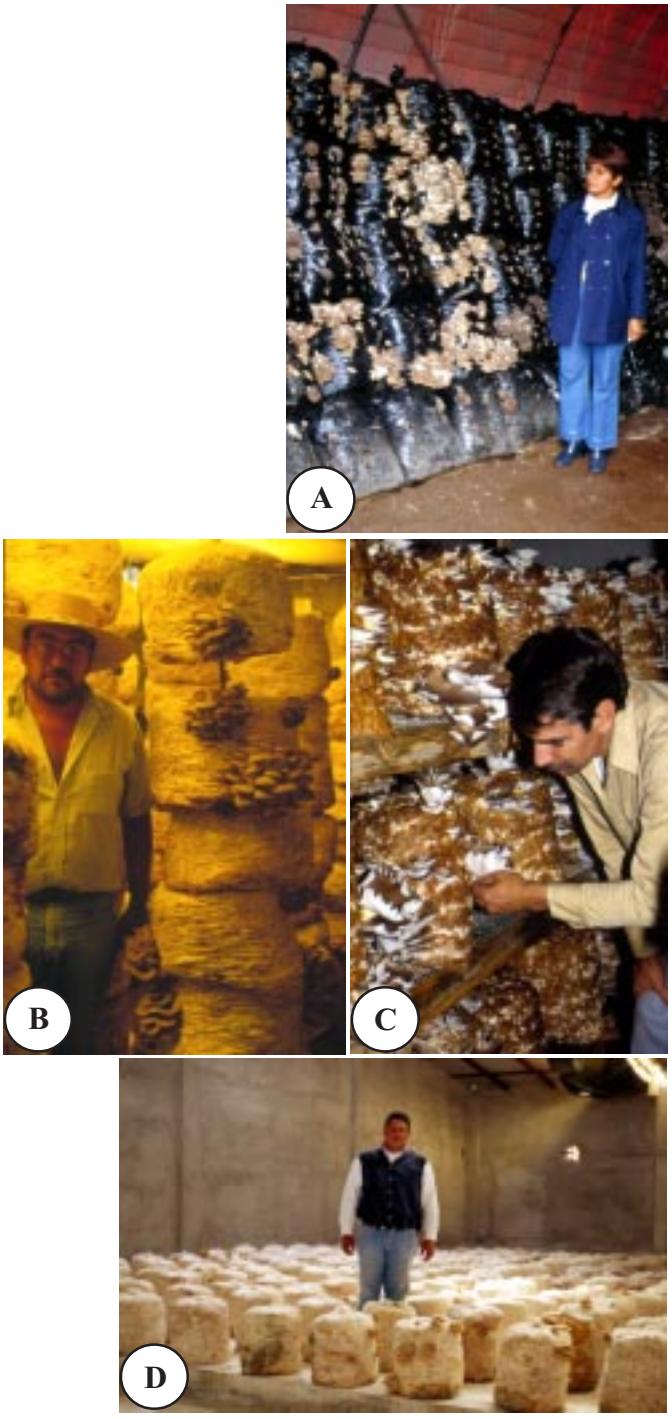

Fig. 3A-D. Cultivation systems for oyster mushrooms (*Pleurotus*) on a large (A) or small (B-D) scale, using stacked plastic bags, stacked plastic bags with a central support, plastic bags in wooden shelves, and plastic bags laid down on the floor.

Three types of RHSs have been identified: 1) Constant growers, 2) Frequent growers, and 3) Occasional growers (**Fig. 4**) .

Lentinula

The cultivation of *shiitake* in Latin America started during the early 1980's in Guatemala, Colombia, and Mexico [17]. Commercial strains of *Lentinula edodes* (Berk.)Pegler from Japan, China, and South Asia are normally used to cultivate *shiitake* mushrooms in polypropylene plastic bags. Growing substrates are prepared with a variety of formulations, based on hardwood sawdust, sawdust from fast-growing tropical trees, and other organic materials as supplements (**Table 4**). Biological efficiencies range from 2-102% (**Fig. 5**). Several attempts have also been made to produce *shiitake* mushrooms commercially using wood logs. At present, small-scale cultivation has also extended to Argentina and Brazil [38].

MUSHROOM PROCESSING

Most mushroom production is sold in the fresh market, after a short refrigeration period. Cold mushrooms (*Agaricus*, *Pleurotus*, *Lentinula*) are directly placed in boxes for

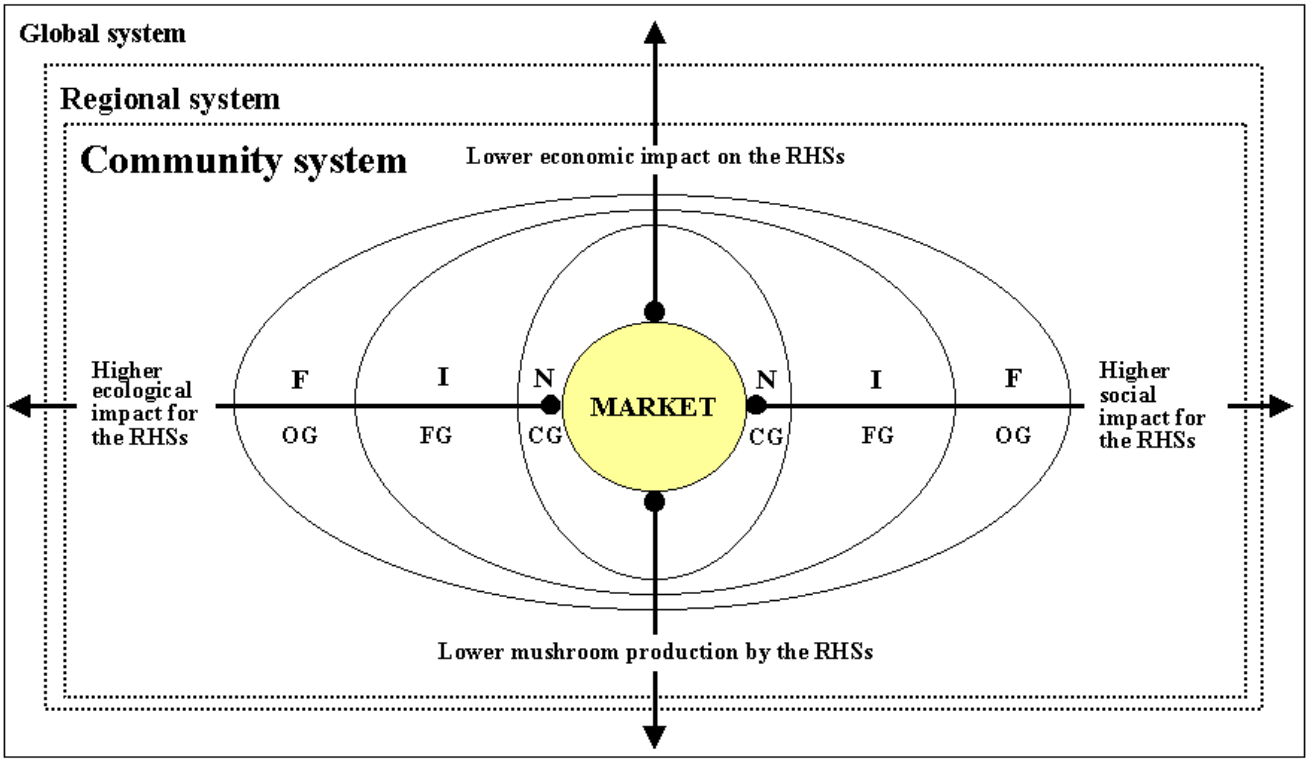

Fig. 4. Fundamental trends of rural mushroom cultivation in Mexico. Rural household systems (RHSs) operating as constant growers (CG), frequent growers (FG), and occasional growers (OG) are normally located near (N), at an intermediate distance (I), or far (F) from the main mushroom market or an urban centre of mushroom consumption, respectively. Depending on this location, RHSs take advantage differentially from the economic, social, and ecological aspects of mushroom cultivation [2].

Table 4. Different formulations which have been used as substrates for the cultivation of shiitake (*Lentinula edodes*) in Latin America.

Substrate	BE (%)	Reference
Carpinus shaving + rice bran + millet (7:2:1)	87.5	Mata *et al*., 1990 [32]
Oak sawdust + wheat bran (12.5%)	53.7	Morales and Martínez-Carrera, 1990 [34]
Bursera sawdust + wheat bran (12.5%)	49.9	Morales and Martínez-Carrera, 1991 [35]
Bursera sawdust + *Quercus* sawdust (1:1) wheat bran (12.5%)	45.9	
Alnus + cotton waste + wheat bran	48.9	Morales *et al*., 1991 [36]
Heliocarpus + cotton waste + wheat bran	65.9	
Nothofagus sawdust + wheat bran + millet seed + chalk (8:1:1:0.2)	3.7-60.4	Pire *et al*., 2001 [38]
Eucalyptus sawdust + wheat bran + millet seed + chalk (8:1:1:0.2)	2.8-26.5	
Araucaria sawdust + wheat bran + millet seed + chalk (8:1:1:0.2)	2.0	
Salix sawdust + wheat bran + millet seed + chalk (8:1:1:0.2)	22.3-25.1	
Oak sawdust + corn-cob + maize stubble + wheat bran + rice meal (7:1:1:0.7:0.3)	102.8	Martínez-Guerrero *et al*., 2002 [29]

BE= Biological efficiency (yield of fresh fruit bodies as a percentage of the dry weight of substrate at spawning).

Fig. 5. Shiitake cultivation in a formulation based on oak sawdust, corn-cob, maize stubble, wheat bran, and rice meal.

local distribution (**Fig. 6A**). They can also be packaged using low-density plastic films for long-distance distribution or longer preservation (**Fig. 6B**) [30]. Mushroom processing started as small-scale canning of *Agaricus* mushrooms in brine around 1950, which was carried out by the company "Hongos de México", through their branch "Monteblanco". This has been followed by large- and small-scale canning of *Agaricus* and *Pleurotus* mushrooms developed during the 1970's to the 1990's in Colombia, Chile, Brazil, Argentina, and Mexico (**Fig. 6C**) [23].

PROSPECTS

Globalisation is opening up new opportunities and bringing new challenges for the Latin American mushroom industry. This is the case of Mexico whose exports have increased irregularly since 1994, when free trade agreements began to be established with other countries, mainly from North America, Europe, and South Asia [21, 22]. Total exports in the year 2000 reached 1,602 tonnes, whereas a significant reduction to 345 tonnes was recorded for 2001 (**Fig. 7A**). However, total imports, mainly of processed mushrooms, increased regularly at a higher rate reaching more than 6,531 and 5,109 tonnes in the years 2000 and 2001, respectively (**Fig. 7B**). Those countries whose mushroom industry is not yet well established will find difficulty to cope with these new competitive circumstances, as well as external economic factors.

Despite the remarkable development of the mushroom industry in Latin America during the last 70 years, mushroom research started up to the early 1980's. Only four countries have reported consistent programmes for germplasm preservation of edible mushrooms. However, the number of strains maintained in their research collections is still very low, considering the megabiological diversity found in the region.

The research on *Agaricus* involves the isolation and characterisation of native strains, as well as breeding using classical and molecular genetics in order to obtain strains showing tolerance to high fruiting temperatures [3, 25, 26]. The study of genes involved in cellulose degradation is starting. Research groups of two institutions from Mexico (College of Postgraduates) and Brazil (University of Paranaese) were considered to participate in the proposal on the *Agaricus* genome project presented recently in the U.K. and the U.S.A.

Fig. 6A-C. Post-harvest management of edible mushrooms in Latin America. A: Fresh oyster mushrooms (*Pleurotus*) placed in boxes for local distribution, normally after refrigeration. B: Packaging "Portobello" (*Agaricus*) mushrooms using low density plastic films for long-distance distribution. C: Rural canning of oyster mushrooms using traditional recipes.

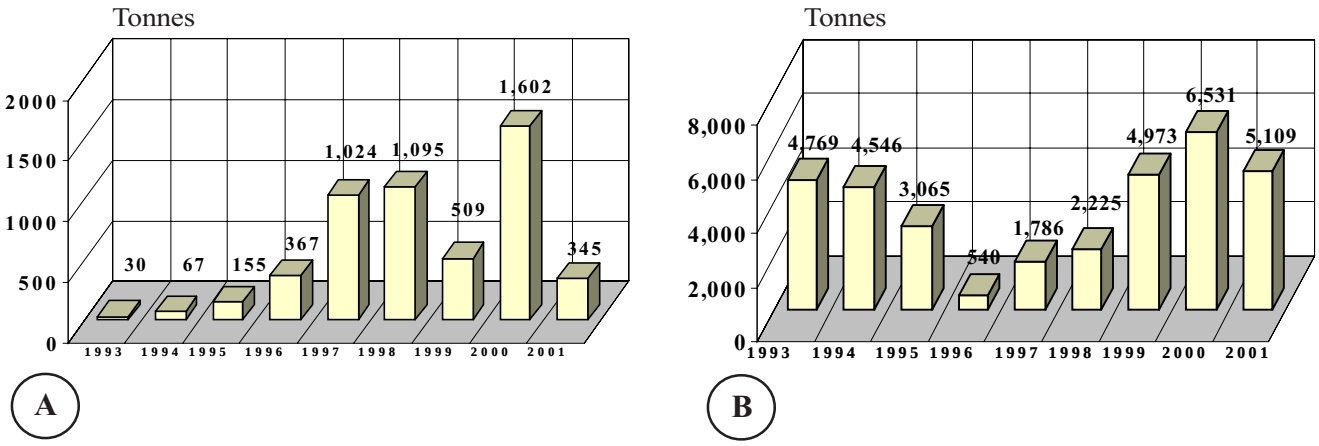

Fig. 7A-B. Balance of trade in Mexico during the period 1993-2001. A: Total exports. B: Total imports.

Most research efforts have been concentrated on *Pleurotus*. Diverse studies are being carried out on: 1) Conventional and molecular taxonomy; 2) Isolation and maintenance of native strains; 3) Genetic diversity; 4) Enzyme production and physiological adaptation; 5) Degradation of polyphenols and production of tannases; 6) Breeding using classical and molecular genetics; 7) Acellulolytic strains; 8) Higher yields and fruit-body colours; 9) Tolerance to high fruiting temperatures; 10) Postharvest physiology; 11) Chemical studies of mushroom products; 12) Local substrate formulations; 13) Mushroom cultivation and sustainable rural development; and 14) Development of marketing strategies [2, 11, 24, 30, 37, 42, 44, 45, 47, 48].

The research on *Lentinula* involves studies on: 1) Enzyme production and physiological adaptation; 2) Antagonistic reactions against moulds; 3) Local substrate formulations and supplementation; and 4) Development of marketing strategies [29, 33, 40].

Experimental work is being carried out in several countries on the cultivation of other mushrooms, such as *Auricularia*, *Ganoderma*, *Volvariella*, *Flammulina*, *Agrocybe*, *Pholiota*, and *Morchella* [43, 44].

Future efforts on basic and applied research should encourage: 1) Germplasm preservation and protection; 2) Further studies at the molecular level; 3) Breeding of strains suitable for cultivation under tropical conditions, as well as strains with reduced sporulation; 4) Control of tropical pests and diseases; 5) Adaptation of cultivation technologies for other cultivated mushrooms; and 6) Studies on mushroom products.

In a globalized world, the development of a more competitive and efficient Latin American mushroom industry would depend on a: 1) Furhter exchange of scientific/technical information; 2) Technology transfer; 3) Organization of growers, 4) Marketing strategies to promote domestic mushroom consumption; 5) Regulations for spawn makers to improve quality standards; 6) Regulations for health risks within farms; 7) Environmental regulations and a furhter implementation in mushroom farms of food quality systems and certification, such as general plan of hygiene, HACCP plan, system of self-control, and external supervi-

sion. If these challenges are overcome, and considering present trends of mushroom cultivation in Latin America, its economic significance for the year 2007 has been estimated to be in excess of 251 million dollars. This means an overall mushroom production of 98 thousand tonnes, and a *per capita* mushroom consumption of 187 g per year. In this way, mushroom biotechnology will certainly have a further contribution to the sustainable development of this region.

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LITERATURE CITED

1. Acosta, L., G. Bustos and D. Portugal. 1988. Aislamientos y caracterización de cepas de *Pleurotus ostreatus* y su cultivo en residuos agroindustriales en el Estado de Morelos. *Rev. Mex. Mic.* 4: 13-20.
2. Aguilar, A., D. Martínez-Carrera, A. Macías, M. Sánchez, L. I. de Bauer and A. Martínez. 2002. Fundamental trends of rural mushroom cultivation in Mexico, and their significance for rural development. Proceed. IV International Conference on Mushroom Biology and Mushroom Products, Cuernavaca, Mexico. 421-431 pp.
3. Albertó, E. 1997. Spawn production in naturally occurring species of *Agaricus* from Argentina. *Micol. Neotrop. Apl.* 10: 33-45.
4. Bermúdez, R. C., N. García, P. Gross and M. Serrano. 2001. Cultivation of *Pleurotus* on agricultural substrates in Cuba. *Micol. Apl. Int.* 13: 25-29.
5. Bernabé-González, T. and J. Arzeta-Gómez. 1994. Cultivo de *Pleurotus ostreatus* sobre cáscara de cacahuate y hoja seca de maíz. *Rev. Mex. Mic.* 10: 15-20.
6. Bernabé-González, T. and R. Garzón-Mayo. 1995. Cultivo de *Pleurotus ostreatus* sobre paja de sorgo y cáscara de cacahuate. *Rev. Mex. Mic.* 11: 165-168.
7. Bernabé-González, T., M. Domínguez and S. Bautista. 1993. Cultivo del hongo comestible *Pleurotus ostreatus* var. *florida* sobre fibra de coco y pulpa de café. *Rev. Mex. Mic.* 9: 13-18.
8. 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.
9. De León, R. 2002. Cultivated edible and medicinal mushrooms in Guatemala. Proceed. IV International Conference of Mushroom Biology and Mushroom Products, Cuernavaca, Mexico. 417-419 pp.
10. de León, R. and C. Rolz. 1988. Mushroom cultivation in Guatemala. *Entwicklung & Ländlicher Raum* 22(2): 18.
11. Guzmán, G., L. Montoya, G. Mata and D. Salmones. 1994. Studies in the genus *Pleurotus*, III. The varieties of *P. ostreatus*-complex based in interbreeding strains and in the study of basidiomata obtained in culture. *Mycotaxon* 50: 365-378.
12. Guzmán-Dávalos, L., D. Martínez-Carrera, P. Morales and C. Soto. 1987. El cultivo de hongos comestibles (*Pleurotus*) sobre el bagazo del maguey de la industria tequilera. *Rev. Mex. Mic.* 3: 47-49.
13. Kües, U. and Y. Liu. 2000. Fruiting body production in basidiomycetes. *Appl. Microbiol. Biotechnol.* 54: 141-152.
14. Labarère, J. E. and U. G. Menini (Eds.). 2000. *Characterization, Conservation, Evaluation, and Utilization of Mushroom Genetic Resources for Food and Agriculture*. The Global Network on Mushrooms, FAO, Bordeaux. 240 pp.
15. Lahmann, O. and D. L. Rinker. 1995. Historical development of commercial mushroom production in Central and South America. *Mushroom Science* 14: 459-466.
16. Martínez-Carrera, D. 1989. Past and future of edible mushroom cultivation in tropical America. *Mushroom Science* 12: 795-805.
17. Martínez-Carrera, D. 2000. Mushroom biotechnology in tropical America. *International Journal of Mushroom Sciences* 3: 9-20.
18. Martínez-Carrera, D. and P. Morales. 1992. Reseña histórica del cultivo comercial de hongos comestibles en Colombia. *Micol. Neotrop. Apl.* 5: 89-95.
19. Martínez-Carrera, D., A. Aguilar, W. Martínez, M. Bonilla, P. Morales and M. Sobal. 2000. Commercial production and marketing of edible mushrooms cultivated on coffee pulp

in Mexico; Chapter 45. Pp. 471-488. *In*: *Coffee Biotechnology and Quality*. Eds. T. Sera, C. Soccol, A. Pandey and S. Roussos. Kluwer Academic Publishers, Dordrecht.

20. Martínez-Carrera, D., A. Aguilar, W. Martínez, P. Morales, M. Sobal, M. Bonilla and A. Larqué-Saavedra. 1998. A sustainable model for rural production of edible mushrooms in Mexico. *Micol. Neotrop. Apl.* 11: 77-96.
21. Martínez-Carrera, D., A. Larqué-Saavedra, M. Aliphat, A. Aguilar, M. Bonilla and W. Martínez. 2000. La biotecnología de hongos comestibles en la seguridad y soberanía alimentaria de México. II Foro Nacional sobre Seguridad y Soberanía Alimentaria. Mexican Academy of Sciences-CONACYT, Mexico, D. F. 193-207 pp.
22. Martínez-Carrera, D., A. Larqué-Saavedra, P. Morales and M. Sobal. 1992. Reconversión en la industria de los hongos?. *TecnoIndustria* 7: 52-59.
23. Martínez-Carrera, D., F. Vergara, S. Juárez, A. Aguilar, M. Sobal, W. Martínez and A. Larqué-Saavedra. 1996. Simple technology for canning cultivated edible mushrooms in rural conditions in Mexico. *Micol. Neotrop. Apl.* 9: 15-27.
24. Martínez-Carrera, D., M. Bonilla, M. Sobal, A. Aguilar, W. Martínez and A. Larqué-Saavedra. 1999. A culture collection of edible mushrooms and its significance for germplasm preservation, breeding, and the development of mushroom cultivation in Mexico. *Micol. Neotrop. Apl.* 12: 23-40.
25. Martínez-Carrera, D., M. Bonilla, W. Martínez, M. Sobal, A. Aguilar and E. Pellicer-González. 2001. Characterisation and cultivation of wild *Agaricus* species from Mexico. *Micol. Apl. Int.* 13: 9-24.
26. Martínez-Carrera, D., M. Sobal and M. Bonilla. 1997. Germplasm preservation and genetic improvement of wild *Agaricus* species in Mexico. *Micol. Neotrop. Apl.* 10: 21-31.
27. Martínez-Carrera, D., P. Morales, E. Pellicer-González, H. León, A. Aguilar, P. Ramírez, P. Ortega, A. Largo, M. Bonilla and M. Gómez. 2002. Studies on the traditional management, and processing of matsutake mushrooms in Oaxaca, Mexico. *Micol. Apl. Int.* 14: 25-42.
28. Martínez-Carrera, D., R. Leben, P. Morales, M. Sobal and A. Larqué-Saavedra. 1991. Historia del cultivo comercial de los hongos comestibles en México. *Ciencia y Desarrollo* 96: 33-43.
29. Martínez-Guerrero, M., D. Martínez-Carrera, J. López-Olguín and P. Ramírez-Carrasco. 2002. Utilización de substratos de aserrín de encino suplementado para el cultivo de shiitake (*Lentinula edodes*). IV Latin American Congress of Mycology (Abstracts), Xalapa, Mexico.
30. Martínez-Soto, G., O. Paredes-López, R. Ocaña-Camacho and M. Bautista-Justo. 1998. Oyster mushroom (*Pleurotus ostreatus*) quality as affected by modified atmosphere packaging. *Micol. Neotrop. Apl.* 11: 53-67.
31. Mata, G. and R. Gaitán. 1995. Cultivo de *Pleurotus* en hojas de caña de azúcar. *Rev. Mex. Mic.* 11: 17-22.
32. Mata, G., D. Salmones and G. Guzmán. 1990. Cultivo del shiitake japonés, *Lentinus edodes*, en bolsas con viruta de madera. *Rev. Mex. Mic.* 6: 245-251.
33. Mata, G., R. Gaitán-Hernández, R. Pérez-Merlo and C. Ortega. 2002. Improvement of shiitake spawn for culturing on pasteurized wheat straw. Proceed. IV International Conference on Mushroom Biology and Mushroom Products, Cuernavaca, Mexico. 303-309 pp.
34. Morales, P. and D. Martínez-Carrera. 1990. Cultivation of *Lentinula edodes* in Mexico. *Micol. Neotrop. Apl.* 3: 13-17.
35. Morales, P. and D. Martínez-Carrera. 1991. *Bursera* sawdust as a substrate for shiitake cultivation. *Micol. Neotrop. Apl.* 4: 41-47.
36. Morales, P., D. Martínez-Carrera and W. Martínez-Sánchez. 1991. Cultivo de shiitake sobre diversos substratos en Mexico. *Micol. Neotrop. Apl.* 4: 75-81.
37. Morales, P., M. Sobal, W. Martínez, A. Larqué-Saavedra and D. Martínez-Carrera. 1995. La cepa CP-50 de *Pleurotus ostreatus*, híbrido comercial seleccionado por mejoramiento genético en México. *Micol. Neotrop. Apl.* 8: 77-81.
38. Pire, D. G., J. E. Wright and E. Albertó. 2001. Cultivation of shiitake using sawdust from widely available local woods in Argentina. *Micol. Apl. Int.* 13: 87-91.
39. Prahm, N. 2002. A labor intensive ecological mushroom production in Bolivia. *Micol. Apl. Int.* 14: 45-52.
40. Ramírez-Carrillo, R. and H. Leal-Lara. 2002. Culture conditions for increasing yields of *Lentinula edodes*. Proceed. IV International Conference on Mushroom Biology and Mushroom Products, Cuernavaca, Mexico. 289-294 pp.
41. Ringeisen, J. G. 1989. Cultivation of champignon in Argentina. *Mushroom Science* 12 (I): 789-794.
42. Salmones, D. and G. Mata. 2002. Detection of extracellular enzymes produced by *Pleurotus* spp. grown on coffee pulp. Proceed. IV International Conference on Mushroom Biology and Mushroom Products, Cuernavaca, Mexico. 213-219 pp.
43. Sánchez-Vázquez, J. E., G. Huerta and L. Calvo. 1995. Potential of *Auricularia* sp. in the recycling of

agroindustrial waste products in the tropics. *Mushroom Science* 14: 877-883.

44. Sánchez, J. E., G. Huerta and E. Montiel (Eds.). 2002. Mushroom Biology and Mushroom Products, Proceedings of the IV International Conference. University of Morelos, Cuernavaca, Mexico. 468 pp.
45. Sobal, M., A. Larqué-Saavedra and M. Soto-Hernández. 1991.Ethylene production by *Pleurotus ostreatus* on axenic culture using coffee pulp as substrate. *Micol. Neotrop. Apl.* 4: 111-117.
46. Sobal, M., P. Morales and D. Martínez-Carrera. 1993. Utilización de los rastrojos de haba y frijol como substratos para el cultivo de *Pleurotus*. *Micol. Neotrop. Apl.* 6: 137-141.
47. Trigos, A. and D. Martínez-Carrera. 1992. Identificación de ergosterol en *Pleurotus ostreatus*. *Micol. Neotrop. Apl.* 5: 11-15.
48. Valencia del Toro, G. and H. Leal-Lara. 2002. Fruit body color in *Pleurotus* spp. hybrid strains obtained by matings of compatible neohaplonts. Proceed. IV International Conference on Mushroom Biology and Mushroom Products, Cuernavaca, Mexico. 151-159 pp.