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A SUSTAINABLE MODEL FOR RURAL PRODUCTION OF EDIBLE MUSHROOMS IN MEXICO

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ABSTRACT

Social, economic, and environmental dimensions are interrelated and involved in sustainability. Long-term experiments or experiences provide fundamental evidence to understand sustainability. We present reliable and organized data from a rural mushroom farm operating commercially during six years (1992-1997). This farm is owned by a cooperative of indigenous peasants from Cuetzalan, Puebla, Mexico. Communities have shown to be capable of adopting mushroom biotechnology, despite peasant inexperience on mushroom cultivation and business administration. Fundamental technologies of mushroom cultivation and marketing can be carried out in rural conditions: 1) Spawn preparation, 2) Mushroom production, and 3) Processing (canning). About 407,871 kg of fresh weight substrate (barley straw and coffee pulp) were bioconverted to 34,626 kg of edible mushrooms (*Pleurotus*), generating around 228,888 kg of spent substrate. Local mushroom consumption

during 1992-1997 increased to 1.06-1.66 kg/year *per capita*, and 4.80-7.53 kg/year per household. In comparison with other crops and agro-industries, mushroom cultivation is also an efficient biotechnological process for using and converting energy or water into a human food. This experience allowed to develop a sustainable model for rural production of edible mushrooms at regional and microregional levels. This model permits the transfer of mushroom biotechnology to indigenous peasant communities for promoting traditional sustainable agriculture, as long as environmental, economic, and social indicators are maintained, and appropriate regional adaptations are carried out.

Key words: Edible mushrooms, *Pleurotus*, rural cultivation, sustainability, traditional agriculture, sustainable agriculture, Mexico.

INTRODUCTION

The concept of sustainability is complex and has recently generated much academic debate. Although a precise definition or interpretation is not yet available, it is generally accepted that there are social, economic, and environmental dimensions involved and interrelated, which are not necessarily incompatible. Sustainable agriculture can be considered as the ability of agricultural systems to remain productive on a long-term basis. Its social dimension, accordingly, can be regarded as the capacity of these systems to sustainably support farming communities. The environmental dimension deals with the interaction between agricultural systems and the natural resource base, while the economic dimension is connected with the economic environment and financial viability of agriculture over time. In order to operationalize these concepts, representative indicators of sustainability, which can be measured and interpreted, should be identified (OECD, 1995; 1997).

Rustic methods have been developed to cultivate a variety of edible mushrooms using agricultural and forestry by-products as growing substrates. Mushrooms produce a wide range of extracellular enzymes capable of degrading these complex by-products (Martínez-Carrera, 1998a, b). In Mexico, rural cultivation of edible mushrooms (*Pleurotus*) started in 1989 in Cuetzalan, Puebla, and it has spread out to other regions of the country in recent years due to its social, economic, and ecological advantages for rural development (Martínez-Carrera, 1999).

Long-term experiments or experiences provide fundamental evidence to understand sustainability. We have monitored a rural mushroom farm operating commercially during six years (1992-1997), in which data were reliable and organized. This period is necessary to be representative, because rural mushroom cultivation using rustic techniques is an intensive biotechnological process subjected to environmental influence, and data may show large variations per year. In the present study, several indicators were identified to develop strategies for assessing and understanding the sustainability of rural mushroom production at regional and microregional levels in Mexico, as well as its contribution to traditional sustainable agriculture.

MATERIALS AND METHODS

General characteristics about the beginning of the technology transfer programme, description of the farm, strains, and evaluation techniques have previously been described (Martínez-Carrera & Larqué-Saavedra, 1990; Martínez-Carrera *et al*., 1991; Martínez-Carrera *et al*., 1992; Martínez-Carrera *et al*., 1993; Aguilar *et al*., 1993; Martínez-Carrera *et al*., 1995; Morales *et al*., 1995a, b; Martínez-Carrera *et al*., 1996a).

The rural mushroom farm studied is located in Cuetzalan, Puebla, Mexico. It is a mountainous region (900-1,600 m altitude) having subtropical climate (mean temperature 18°-24°C; mean precipitation 2,250 mm/year). The farm is owned by an organized cooperative of indigenous peasants speaking native languages, and having a normal diet based on maize, beans, and chilli.

Members of the cooperative were trained to prepare spawn, to cultivate edible mushrooms (*Pleurotus*) using rustic techniques, and to process fresh mushrooms by canning. Commercial production of spawn and oyster mushrooms in the rural farm started in 1992, whereas experimental mushroom processing began in 1997. Cultivation techniques using local growing substrates have previously been described (Martínez-Carrera, 1985, 1987, 1989; Martínez-Carrera *et al*., 1996b). Biological efficiency was determined by expressing the yield of fruit bodies (fresh weight) as a percentage of the dry weight of substrate at spawning (Tschierpe & Hartmann, 1977). Financial analysis in U.S.A. dollars (USD) was carried out according to basic criteria established by Gittinger (1978).

RESULTS AND DISCUSSION

Straw and coffee pulp were main agricultural by-products available in the region. These substrates were used for mushroom cultivation, either independently or mixed in different proportions (**Table 1**). Wheat and barley straw were available throughout the year, but their prices varied

Table 1. Substrates used for mushroom cultivation in a rural farm from Cuetzalan, Puebla, during the period 1992 (January)-1997 (December).

Year	Substrates (kg)				Spent substrate (fresh weight, kg)	
	Straw		Coffee pulp			
	Dry weight	Fresh weight	Dry weight	Fresh weight	Straw	Coffee pulp
1992	14,491.9	83,287.0	na	na	46,363.0	na
1993	11,079.7	63,677.0	331.4	2,986.3	35,446.8	1824.9
1994	8,781.6	50,469.0	231.2	2,083.5	28,094.5	1,273.2
1995	11,946.1	60,731.0	917.3	8,264.5	33,806.9	5,681.8
1996	19,263.9	69,294.5	491.9	4,432.5	38,573.9	2,708.6
1997	16,180.1	58,201.8	493.2	4,444.3	32,398.9	2,715.8
Total	81,743.3	385,660.3	2,465.0	22,211.1	214,684.0	14,204.3

na= Coffee pulp was not available this year due to extreme climatic conditions.

significantly ($ 0.06-0.10 per kg, dry weight). The cheapest commercial prices in this region every year, were recorded during September-December, so this is the period recommended to buy straw in order to save costs in the long run. Fresh coffee pulp was only available seasonally (October-January) at no cost, and small amounts were dried to be used out of season. Substrate quality was essential to reduce contamination, and to obtain good yields. During the period 1992-1997, about 407,871 kg of substrate (fresh weight: 94.6% of straw, and 5.4% of coffee pulp) were used, from which 228,888 kg (56.1%) of spent substrate were generated. The spent substrate was composted, either natural composting or vermi-composting, to produce an organic fertilizer or soil conditioner for crop soils.

The laboratory of the farm produced spawn for mushroom production and for selling to other rustic farms in the region or to indigenous peasants for domestic cultivation (**Table 2**). The local market for mushroom

Table 2. Spawn production in a rural mushroom farm from Cuetzalan, Puebla, during the period 1992 (January)-1997 (December).

Year	Number of jars[1]	Jars/bag ratio [2]	Amount of spawn per bag (g)	Jars sold	
				Number	Incomes ($)
1992	14,230	0.8	256	144	43.20
1993	6,553	0.6	192	1,090	327.00
1994	5,000	0.5	160	1,872	561.60
1995	4,985	0.6	192	9,325	2,797.50
1996	5,676	0.4	128	3,648	1,094.40
1997	4,426	0.5	160	912	364.80
Total	40,870	0.5[3]	181[3]	16,991	5,188.50

[1] Each jar contained *ca*. 320 g of grain spawn (wheat kernels), whose price varied from $ 0.30 (1992-1996) to $ 0.40 (1997).

[2] Every plastic bag contained an average of 6.6 kg of fresh weight substrate.

[3] Average data.

spawn was irregular. A total of 57,861 jars of spawn (*ca*. 18,515 kg) were produced during 1992-1997, from which 16,991 jars (*ca*. 5,437 kg) were marketed at an average price of $ 0.35 per jar, generating incomes for $ 5,188. Spawning was done by hand, at the average rate of *ca*. 30 g/kg fresh substrate weight.

A total production of 34,626 kg of fresh oyster mushrooms were marketed during the period 1992-1997 (69 months). Mushroom production per month varied from 111-945 kg. Average mushroom yield per bag (6.6 kg fresh weight substrate) was 0.582 kg, indicating a biological efficiency of 42% (**Table 3**). This is a low commercial efficiency, which may be attributed to high temperatures during summer season, pests and diseases, as well as to rustic techniques used. In general, there was a correlation between mushroom production and mean temperatures (**Fig. 1**). Higher production was observed at lower maximum and minimum mean

Table 3. Commercial production of oyster mushrooms in a rural farm from Cuetzalan, Puebla, during the period 1992 (January)-1997 (December).

Year	M	Fresh weight substrate (kg)	Number of spawned bags[1]	Mushroom production (kg)	Yield per bag (kg)	BE (%)
1992	9	83,287.0	16,131	5,169.1	0.320	35
1993	12	66,663.3	10,665	4,611.1	0.432	40
1994	12	52,552.5	8,408	5,532.9	0.658	61
1995	12	68,995.5	8,043	5,905.7	0.734	44
1996	12	73,727.0	11,844	7,225.4	0.610	36
1997	12	62,646.1	8,351	6,182.1	0.740	37
Total	69	407,871.4	63,442	34,626.3	0.582[2]	42[2]

M= Number of months. BE= Biological efficiency.

[1] Every plastic bag contained an average of 6.6 kg of fresh weight substrate.

[2] Average data.

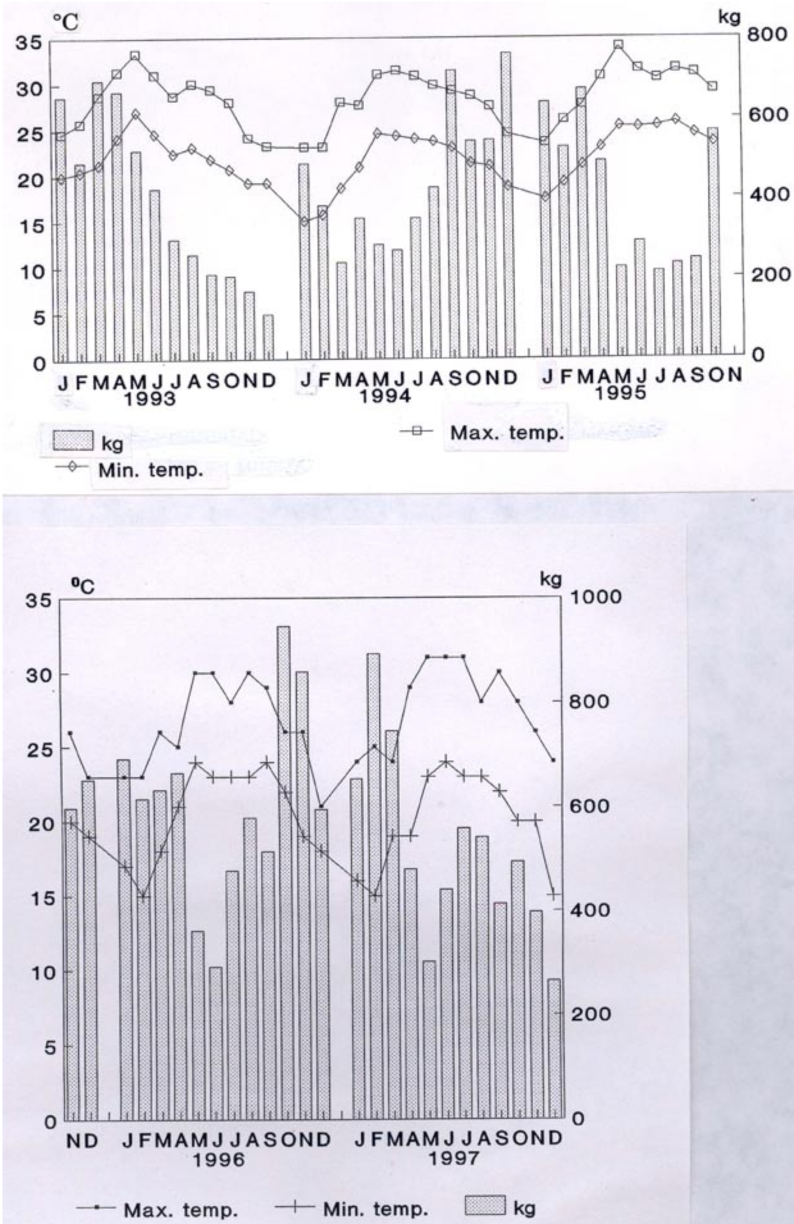


Fig. 1. Commercial mushroom production per month in the rural farm from Cuetzalan, Puebla, correlated with maximum and minimum mean temperatures during the period 1993-1997.

temperatures (October-March), whereas lower production corresponded with higher mean temperatures (April-July). During the period 1993-1997, the maximum temperature ranged from 21°-33°C, while the minimum temperature varied from 15°-24°C.

In 1992, the rural mushroom farm began to operate commercially with seven trained indigenous peasants, one in the laboratory and the other six involved in mushroom production. Four years later (1996), the farm became more efficient as mushroom production increased 40% (Table 3), while the number of trained peasants was reduced 43%, from seven to four (**Table 4**). At the same time, the minimum wage improved 115%. The total amount of salaries paid to trained peasants, during 1992-1997, was $ 17,845.

Production and operation costs were $ 19,091 during 1992-1997, and included raw materials and energy (gas, electricity), administration and travelling expenses, maintenance, and marketing (**Table 5**). The highest proportion from overall production and operation costs was covered by salaries (48%), as well as raw materials and energy (33%),

Table 4. Number of jobs generated, including salaries, for the commercial production of oyster mushrooms in a rural farm from Cuetzalan, Puebla, during the period 1992 (January)-1997 (December).

Year	Number of workers			Salaries
	Laboratory for spawn production	Mushroom production	Average minimum wage ($)	($)
1992	1	6	1.30	3,321.50
1993	1	6	1.00	2,419.87
1994	1	4	1.30	2,329.36
1995	2	3	1.80	3,186.98
1996	1	3	2.80	4,088.57
1997	1	2	2.40	2,498.81
Total			1.70	17,845.09

Table 5. Costs of production and operation, excluding salaries, in a rural commercial farm from Cuetzalan, Puebla, during the period 1992 (January)-1997 (December).

Year	Raw materials and energy	Administration expenses	Travelling expenses	Maintenance	Marketing
1992	1,434.98	83.19	43.60	9.30	366.00
1993	1,521.60	88.41	169.84	69.30	107.93
1994	1,403.11	137.47	408.45	459.24	193.30
1995	2,297.99	134.45	473.40	385.71	290.08
1996	3,273.04	202.62	473.90	704.58	103.95
1997	2,487.73	282.64	472.85	877.09	135.75
Total ($)	12,418.45	928.78	2,042.04	2,505.22	1,197.01

and accordingly efforts to make a rural farm more efficient should be concentrated on these factors (**Fig. 2**). Marketing had a low proportion (3%), as oyster mushrooms were sold locally. If mushroom production increases maintenance, travelling expenses, and marketing, would rise proportionally.

A financial analysis of the rural farm for the period 1992-1997, indicated a total economic value of $ 77,513. Gross incomes were $ 40,576, production costs $ 36,936, and profits $ 3,639 (**Table 6**). Average cost-benefit ratio was positive (1.10). In 1996, the cost-benefit ratio was negative as raw material acquisition was not properly planned. Mushroom production represented about 70% from total profits, while spawn production around 30%. Most mushrooms were marketed in the town of Cuetzalan, increasing average mushroom consumption to 1.32 kg/year *per capita*, and that per household to 6 kg/year (**Fig. 3**). This is relatively high if compared to the estimated *per capita* mushroom consumption in Mexico (0.346 kg/year). Canning technology for mushroom processing has recently been transferred to the cooperative, providing additional advantages to establish marketing strategies at national or international level.

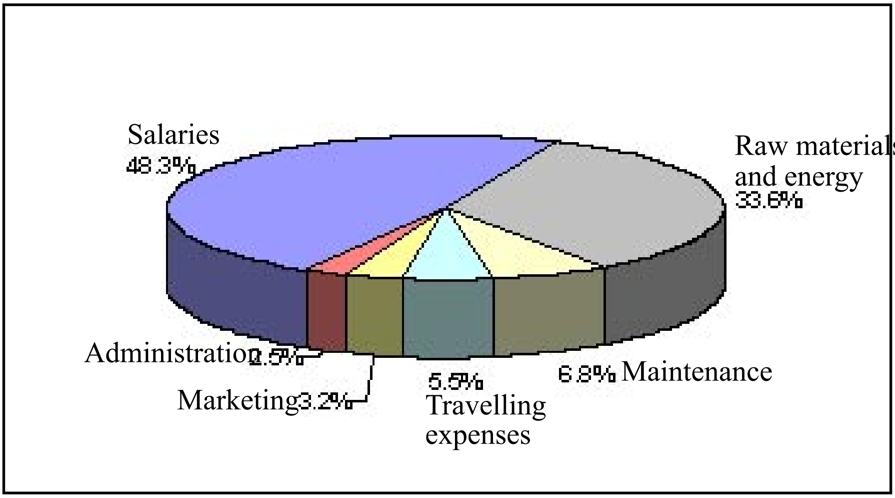


Fig. 2. Main factors considered and their proportions in overall production and operation costs.

Table 6. Financial analysis of the commercial mushroom production in a rural farm from Cuetzalan, Puebla, during the period 1992 (January)-1997 (December).

Year	Production costs ($)	Gross incomes ($)	Profits ($)			Cost-benefit ratio
			Fresh oyster mushrooms	Spawn	Total	
1992	5,258.61	5,741.81	444.24	38.96	483.20	1.09
1993	4,376.95	5,099.90	451.35	271.60	722.95	1.16
1994	4,930.93	5,505.79	167.22	407.63	574.85	1.11
1995	6,768.57	7,541.42	394.25	378.59	772.84	1.11
1996	8,846.66	8,418.82	-360.10	-67.74	-427.84	0.95
1997	6,754.87	8,268.83	1,439.64	74.32	1,513.96	1.22
Total	36,936.59	40,576.57	2,536.60	1,103.36	3,639.96	1.10[1]

[1] Average data.

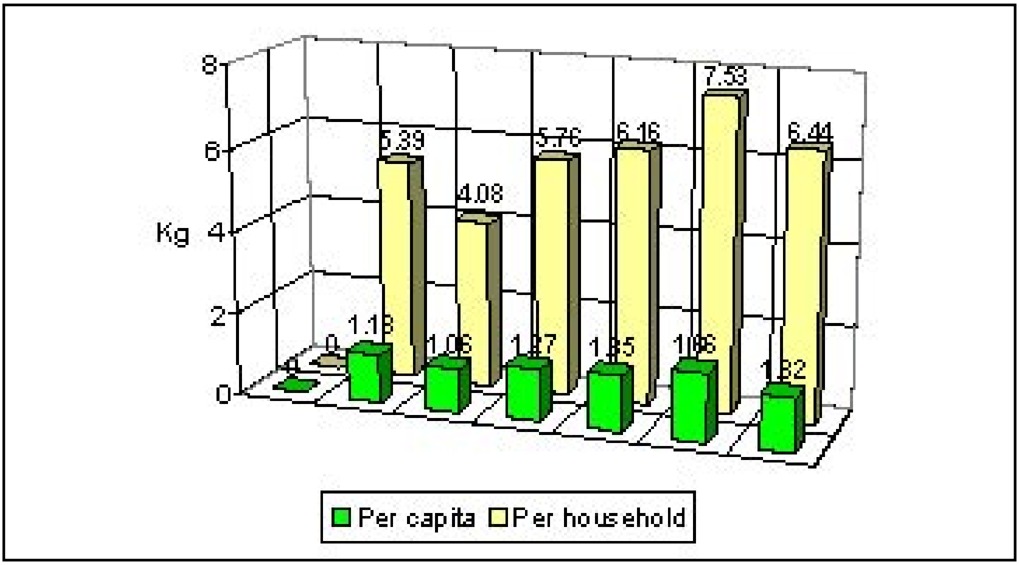
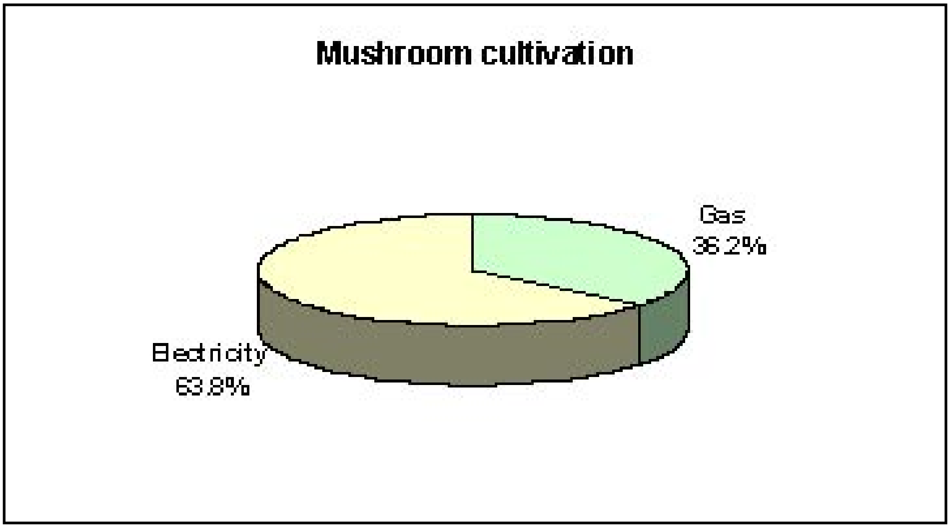


Fig. 3. Mushroom consumption during 1992-1997, *per capita* and per household, in the town of Cuetzalan, Puebla (INEGI, 1990).

Main direct energy sources consumed for mushroom cultivation in a rural farm are electricity and gas. Most energy (93%) was spent in mushroom production during 1992-1997, $ 3,183 for electricity (63%; average price: $ 0.05/kWh) and $ 1,464 for gas (36%; price range: $ 0.03-0.15/kg). Spawn production represented 7% from all energy spent, $ 8.49 for electricity (0.2%) and $ 341 for gas (99.8%) [**Figs. 4-5**]. Energy costs per year ranged from $ 482-1,248. According to these data, in ecological and financial terms, energy-use and conversion efficiency is more effective in spawn production than in mushroom production. It may, therefore, be recommended to improve facilities for spawn production in order to take advantage of the regional market.



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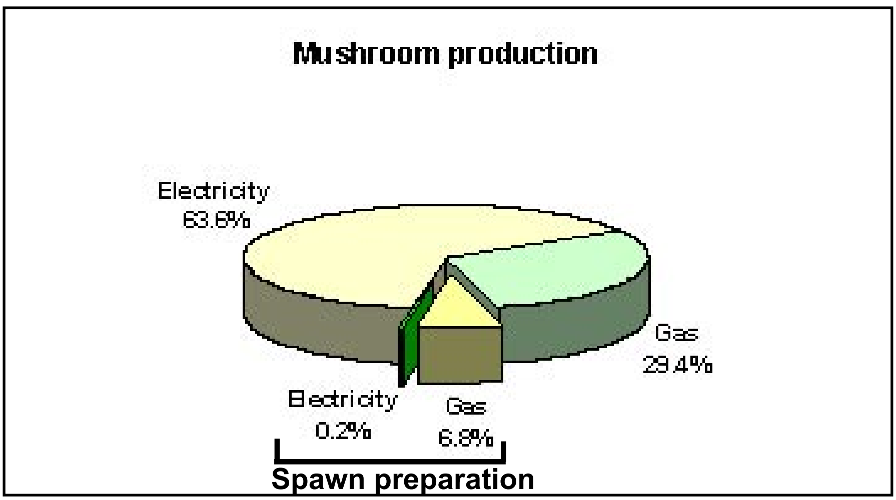

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Figs. 4-5. Energy consumption during commercial cultivation of oyster mushrooms in a rural farm from Cuetzalan, Puebla [period: 1992 (January)-1997 (December)]. 4: Overall process of mushroom cultivation. 5: Proportion of energy consumed for spawn preparation and mushroom production. Data for spawn (number of jars) and mushroom production per year are shown in Tables 2-3, respectively.

Considering that water resources in Mexico are limited, and having an increasing demand in most regions, water consumption is a key factor in any production process. Most water consumed in Cuetzalan, Puebla, comes from surface sources. Mushroom production, including pasteurization and watering, had an estimated water consumption of 948,494 L during 1992-1997, whereas spawn production required 28,930 L. Water consumption is considerably higher in mushroom production (*ca*. 97%) than in spawn production (*ca*. 3%) [**Fig. 6**]. Overall data indicated 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

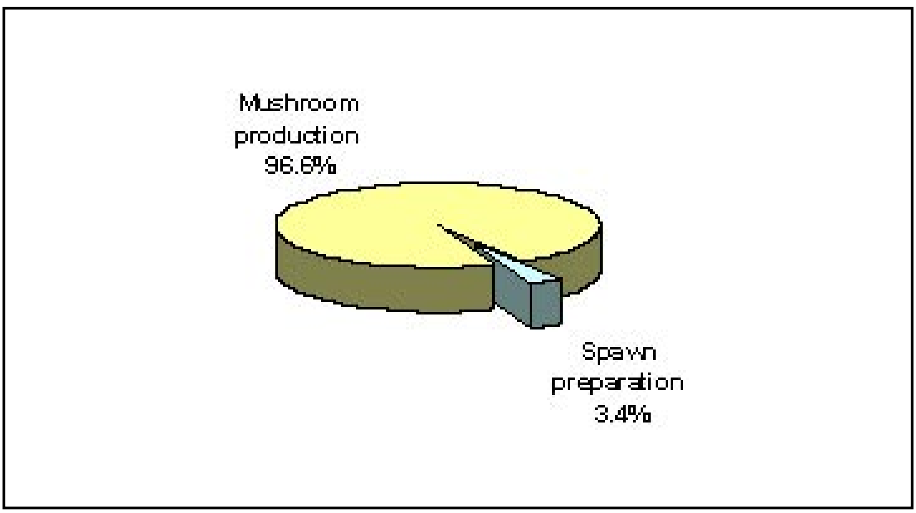


Fig. 6. Estimated proportions of water consumption during the commercial production of oyster mushrooms in a rural farm from Cuetzalan, Puebla [period: 1992 (January)-1997 (December)].

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). In other words, the production of 1 kg of beef requires 3,571 times more water than the amount needed to produce 1 kg of oyster mushrooms. Similarly, taking into account the protein content of these foods, 1-515 L of water are needed to produce one gram of protein (**Table 7**). Several strategies have been undertaken to improve water-use efficiency, as well as reuse and recycling, within the farm.

Table 7. 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.

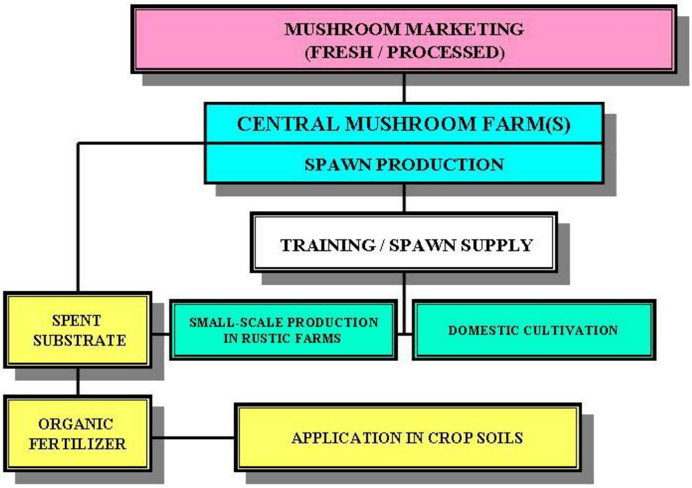
Product	Litres of water/kg	Protein content[a] (g)	Litres of water per gram of protein
Oyster mushrooms (*Pleurotus*)	28	2.7	1.0
Potatoes	500[b]	2.1	23.8
Wheat	900[b]	14.0	6.4
Alfalfa	900[b]	6.0	15
Sorghum	1,110[b]	11.0	10.0
Corn	1,400[b]	3.5	40.0
Rice	1,912[b]	6.7	28.5
Soybeans	2,000[b]	34.1	5.8
Broiler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

Overall data analysis has shown that fundamental technologies of mushroom cultivation and marketing can be carried out in rural conditions: 1) Spawn preparation, 2) Mushroom production, and 3) Processing (canning). During the period 1992-1997, about 407,871 kg of fresh weight substrate (straw, coffee pulp) were inoculated with 13,078 kg of spawn, which yielded 34,626 kg of fresh mushrooms (**Fig.7**). This experience has allowed to develop a sustainable model for rural production of edible mushrooms at regional and microregional levels (**Figs. 8-9**), whose social, economic, and ecological advantages have previously been discussed (Martínez-Carrera, 1999). The communities from Cuetzalan, Puebla, have shown to be capable of adopting mushroom biotechnology, despite peasant

Fig. 7. Estimated amount of substrates, spawn, and fresh oyster mushrooms produced during the period 1992-1997, in Cuetzalan, Puebla, using rustic technologies.



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Figs. 8-9. 8: A sustainable model for rural production of edible mushrooms. 9: Rural mushroom cultivation in Mexico.

inexperience on business administration and mushroom cultivation.

Several environmental, economic, and social indicators were identified and interpreted to assess sustainability. As rural mushroom cultivation is a variable and intensive biotechnological process, the performance of these indicators evaluating a basic factor or factors should be studied for at least five years in a particular region or microregion. Under conditions studied, below or over critical values of representative indicators, the model becomes unsustainable or inefficient over time (**Table 8**). Environmental indicators analyzed were biological efficiency (ž 32%), degradation rate (ž 31%), contamination rate (20%), energy-use efficiency (12%, as a proportion from the total production cost), water-use efficiency (ž 28 L/kg), temperature (minimum 15^{o}C; maximum 33^{o}C), and relative humidity (ž 70%). Cost-benefit ratio (ž 1.0) was the main economic indicator, whereas social indicators included minimum mushroom consumption (*ž* 0.914 kg/year *per capita*; ž 4.100 kg/year per household), and labour efficiency (3 workers; an average minimum production of 1,689 kg/worker/year). If efficient technologies and enough capital are available, the potential market (local, national, international) can be estimated to increase rural mushroom production.

If rural mushroom production is scaled up, there will be a more efficient performance and control of representative indicators. Efficiency of this mushroom farm is expected to improve gradually. Future challenges include: 1) To develop a more efficient administration system within the cooperative; 2) To allow timely maintenance of the farm, and timely acquisitions of raw materials; 3) To improve facilities for spawn preparation, mushroom production (environmental control during warmer months), and processing; 4) Rustic technologies should be scaled up to make cultivation processes more efficient; 5) To establish marketing strategies for fresh and canned mushrooms. The model for rural production of edible mushrooms permits the transfer of mushroom biotechnology to indigenous peasant communities for promoting traditional sustainable agriculture at regional or microregional levels, as long as environmental, economic, and social indicators are maintained and appropriate regional adaptations are carried out.

Recycling of nutrients is a fundamental process within balanced ecosystems carried out by detritus feeders and decomposers, in which

Table 8. Environmental, economic, and social indicators which contributed to understand the sustainability of the model for rural production of edible mushrooms using rustic technologies in Cuetzalan, Puebla, during the period 1992-1997.

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.

fungi play an important role (Nebel & Wright, 1998). In this context, the major contribution of mushroom biotechnology to ecosystem/agricultural system sustainability is connected with the disposal and recycling of agricultural and forestry by-products. In comparison with other crops and agro-industries, mushroom cultivation is also an efficient biotechnological process for using and converting energy or water into a human food. Accordingly, it can be promoted in those regions of acute poverty where energy and water shortages are normally present.

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