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Mico-Lógica Oaxaca: a Mexican experience on the rural cultivation of edible and medicinal mushrooms using low-cost technology

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INTRODUCTION

The cultivation of edible and medicinal mushrooms is becoming more important worldwide due to successful technology transfer, as well as to the growing evidence on their nutritional and functional properties[1,2,11]. The rural production of edible mushrooms in Mexico started in 1989 at the town of Cuetzalan, State of Puebla, in the northern mountains. The model of technology transfer was developed by Martínez-Carrera and Larqué Saavedra[4], and it has been shown to be successful in many peasant, indigenous, rural and even suburban communities across the country. This model considers the traditional consumption of edible mushrooms, and promotes their cultivation and processing for food security through own consumption and income generation by selling mushrooms locally or regionally[6,10]. The social, economic and ecological impact of the model on Mexican family farming has been great due to an increasing national mushroom demand. The model has been shown to be sustainable and, at present, there are more than 6,000 small mushroom producers in central Mexico[5,7,8].

MICO-LÓGICA OAXACA

Mico-Lógica Oaxaca is an initiative to promote the cultivation and benefits of edible and medicinal mushrooms, which started in 2010 involving production, training and diffusion. The initiative is based on authors' (J. Mathieu, J. Jiménez) previous experience in processing mushroom extracts, as well as the organization of the Annual Mushroom Fair since 2000 at the village of San Antonio Cuajimoloyas, Oaxaca, Mexico. The main objective of this initiative is mushroom production for personal or family consumption. Edible mushrooms are thus considered an important dietary supplement for producers and consumers. They improve community and regional food security. The promotion of mushroom cultivation and processing in rural settings near Oaxaca, using a low-cost technology, is carried out by family units in charge of the production rooms.

REGIONAL APPROACH

Activities, involving households, are carried out mainly from a regional organization of towns called "Pueblos Mancomunados", located at the "Sierra de Juárez" mountain range (**Fig. 1**). Most work is focused on the village "Benito Juárez" (*ca.* 3,000 m altitude), about 55 km from the capital city of Oaxaca, Mexico. The "Pueblos Mancomunados" are indigenous communities from three Municipalities, namely: Santa Catarina Lachatao, San Miguel Amatlán and Santa María Yavesía. Communities are settled in eight villages having around 3,500 inhabitants. Communal territory covers an area of 29,430 ha, of which 5,212 ha are only used for logging. Temperate forests are predominant showing a pine-oak ecotone, 2,000-3,200 m altitude (latitude 17º 06' 05'', 17º 17' 32'' north; longitude 96º 20' 41'', 96º 32' 24'' west). Households from the southern mountain range of Oaxaca, as well as from the Central Valley region, also participate through courses on mushroom cultivation and mushroom production.

THE MUSHROOM PROJECT

This project from Mico-Lógica Oaxaca aims at promoting the medicinal, nutritional and environmental uses of edible mushrooms and their importance for humanity and nature. A long term vision is to organize a network of edible and medicinal mushroom producers capable of managing processing technologies for satisfying the local and regional consumer demand. These objectives are achieved by providing ongoing technical advice and training; spawn supply; processing services and training for elaborating mushroom products; marketing support for mushrooms and their products in the internet and health food stores; and information about the benefits from mushrooms. The project also aims to promote alternative sources of income and employment opportunities in rural and semi-rural areas through low-tech cultivation of *Pleurotus ostreatus* (Jacq.) P. Kumm. and *P. pulmonarius* (Fr.) Quél. (oyster mushrooms), *Lentinula edodes* (Berk.) Pegler (shiitake), *Flammulina velutipes* (Curtis) Singer (enokitake), and *Ganoderma lucidum* (Curtis) P. Karst. (reishi), which require minimal monetary investment. Processed products are promoted along with information about nutritional, medicinal and environmental properties of mushrooms.

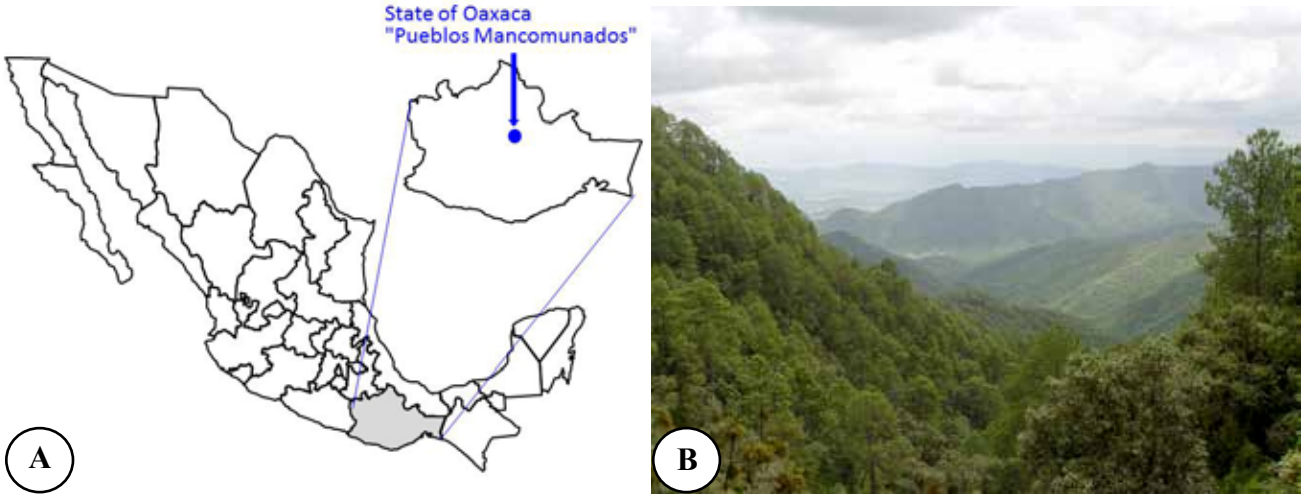

Fig. 1. Activities of Mico-Lógica Oaxaca are focused on rural communities organized as "Pueblos Mancomunados" from the State of Oaxaca (A), located at the "Sierra de Juárez" mountain range (B) in Mexico.

LOW-TECH MUSHROOM CULTIVATION

The initial investment is minimal and accessible to the majority of people. Cultivation facilities can be anything from adobe houses to wood cabins, adapted with cardboard and newspaper for insulation, and lined with polyethylene to maintain moisture and heat as constant as possible. Windows are protected with polyethylene mosquito nets, providing natural ventilation. Domestic fans are used for ventilation during the production of basidiocarps. Metal drums (200 L) are used outdoors for steam treatment of substrates, and they are just held closed with a bicycle tube.

The substrate for the cultivation of *Ganoderma*, *Lentinula*, *Flammulina*, and *Pleurotus* is a mixture of sawdust from *Quercus* and *Alnus*. The sawdust is made from tree byproducts using a chainsaw. *Agave* bagasse, a byproduct of "mezcal" production (local liquor), and corn cobs are substrates also used for the cultivation of *Ganoderma* and *Lentinula*. *Pleurotus* species are also cultivated on oat straw, as well as on maize, pea, and black bean stubble, depending on seasonal availability. A protein supplement may be used to improve mycelial colonization, and it is made from wheat bran in a proportion ranging from 5-20%, and raw or processed sugar cane ranging from 0.5-1%. Low temperatures help supplementation with no adverse effects. Although forest mushrooms prefer mild acid conditions, sometimes lime and gypsum between 1-1.5% are added to the substrates.

Pre-wetted substrates for *Pleurotus* cultivation are steamed within metal drums (*ca.* 2 h), cooled, and spawned on a metal sheet, disinfected with a solution of 10% domestic bleach. Spawn rate is normally 2.5% (w/w, wet substrate), and the spawned substrate (*ca.* 12 kg) is introduced into plastic bags. Tiny holes are made on

the bags two days after spawning. The incubation period varies from 3 to 5 weeks, depending on the strain and substrate used, as well as on weather conditions. Mushroom growing rooms have natural light (just enough to read and write), and little air circulation. Mushrooms are produced on bags stacked one on top of the other with a rope, forming rows and allowing efficient use of the production space. Suitable relative humidity for basidiocarp development is kept by watering the floor two or three times per day or by using 5-liter manual sprinklers, depending on weather conditions. The biological efficiency reached with *Pleurotus* cultivation can be above 100%, using a substrate of *Agave* bagasse from fermentation (78.5%), oat straw (15%), wheat bran (5%), and lime, gypsum and ash (1.5%) [**Fig. 2**]. In order to obtain the best quality, suitable humidity is provided during mushroom production. The production cycle lasts 1-2 months.

Lentinula edodes is cultivated on sawdust (66%) and *Agave* bagasse (10%), supplemented with corn-cobs (2.5%), wheat bran (20%), and lime, gypsum and ash (1-1.5%). Sawdust from *Quercus* spp. or *Alnus* spp. is soaked in 200-liter drums for 4-12 h, thereafter it is mixed thoroughly by hand with the rest of supplements. The mixture (2-5 kg) of about 50-65% moisture is then placed into plastic bags (2-4 kg) with a ring at the top (*ca.* 5 cm diameter, made from a hosepipe), which is covered with cotton and recycled paper as rustic air filter. These bags are steamed in 200-liter metal drums for 8 h at 90 C (www.engineeringtoolbox.com/boiling-points-water-altitude-d_1344.html). Steamed bags are inoculated (1.5% spawn rate) and incubated in the growing rooms for 2-6 months. The induction of the first mushroom flush is performed by continuous watering of production units when brown mycelial coats, bumps or primordia are developed. The other mushroom flushes are induced by immersion in cold water for 12 h, two weeks after the production of basidiocarps. Four harvests may be obtained in the rooms for mushroom production, about 530 g of fresh mushrooms per bag in total, reaching a biological efficiency of 75.7% (**Fig. 3A-C**). Shiitake production is also being done in natural areas using semi-open structures built with local materials, allowing better ventilation.

The cultivation of shiitake is also carried out on hardwood logs (*Quercus* spp., *Alnus* spp.) of manageable size. Logs (10-15 x 80-90 cm) are drilled and inoculated with the colonized substrate from the above-mentioned bags. Inoculated holes are then covered with bees wax. Logs are then incubated for 1-2 years for oak wood, or 7-8 months for alder wood. After that, the production of shiitake mushrooms is induced by immersion in cold water for 12 h. The biological efficiency is greater on oak wood than on alder wood (**Fig. 3D**); however, it does not exceed 35% making cultivation on logs a secondary alternative.

The cultivation *Ganoderma lucidum* (reishi) and *Flammulina velutipes* (enokitake) is carried out in similar way as shiitake bags, excepting for the substrate composition. In this case, the proportion of oak or alder sawdust is 42.5%, *Agave* bagasse (45%), wheat bran 10%, gypsum 2%, and lime 0.5% (*ca.*, 2 kg substrate/bag). The incubation and production of *Ganoderma* basidiocarps have been very slow due to low temperatures at 3,000 m altitude, reaching a biological efficiency of 36.5% and an average yield of 230 g per production unit (**Fig. 4A**). However, in the case of *Flammulina*, the first mushroom flush is produced a month after inoculation,

Fig. 2. Low-cost cultivation of *Pleurotus* spp. in the community of "Benito Juárez", State of Oaxaca, Mexico.

Fig. 3. Low-cost cultivation of shiitake (*Lentinula edodes*) using sawdust (A-C) or hardwood logs (D) as substrates in the community of "Benito Juárez", State of Oaxaca, Mexico.

reaching a biological efficiency of 66.6% and an average yield of 360 g per production unit (**Fig. 4B**).

Fresh harvested mushrooms of *Pleurotus*, *Lentinula*, and *Flammulina* are trimmed from substrate remnants and kept at 4 C until marketed in the village of Benito Juárez, surrounding communities of Latuvi, la Nevería and San Antonio Cuajimoloyas, or about 55 km away at Oaxaca city. Mushrooms are also processed as pickles (traditional recipes containing mushrooms, nopal, chili, tomato, thyme, bay-leaves, olive oil, apple vinegar); or dried for soups (dry mushroom powder containing garlic and thyme), teas [dry mushroom powder from seven species: *P. ostreatus*, *L. edodes*, *F. velutipes*, *Ganoderma lucidum*, *G. applanatum* (Pers.) Pat., *Trametes versicolor* (L.) Lloyd, *Fomitopsis pinicola* (Sw.) P. Karst.], extracts (hydro-ethanolic extracts from five species: *P. ostreatus*,

Fig. 4. Low-cost cultivation of *Ganoderma lucidum* (A), reishi, and *Flammulina velutipes* (B-C), enokitake or winter mushroom, using sawdust and hardwood logs as substrates in the community of "Benito Juárez", State of Oaxaca, Mexico.

L. edodes, *G. applanatum*, *T. versicolor*, *F. pinicola*; vitamin C is added), and chocolates (organic chocolate containing mushroom extracts from *P. ostreatus*, *L. edodes*, *G. lucidum*, *T. versicolor*, *F. pinicola*, red and white cocoa, amaranth, oat, vanilla, cocoa butter, and honey) [**Fig. 5**]. These products are also marketed every year at the Traditional Mushroom Fair at San Antonio Cuajimoloyas village, Pueblos Mancomunados, in the northern mountains "Sierra de Juárez" of the State of Oaxaca, Mexico (**Fig. 6**). Training workshops for mushroom cultivation are regularly organized at the community of Benito Juárez, as well as at the mushroom fair. Young people and adults from many regional or national places are taught about low-cost production techniques and the culinary, medicinal and ecological importance of mushrooms. They are also given fully colonized production units for mushroom cultivation at home, which has become popular and very important for social recognition about mushrooms.

Disinfection of production rooms after harvesting is achieved using hydrated lime on the floors and a solution of 10% domestic bleach on structures and walls. Commercial mosquito-repellent coils, non-toxic sticky traps, and UV lights with electric wire grids are used to get rid of insects and flies during the harvesting period. A water solution of biological powder soap is also efficient

Fig. 5. Mushroom products elaborated by Mico-Lógica Oaxaca in the community of "Benito Juárez", State of Oaxaca, Mexico. A: Dried shiitake mushrooms. B: A mixture of seven dried mushrooms for tea preparation. C: Oyster mushrooms pickled at the community. D: A mixture of five mushroom hydro-ethanolic extracts. E-F: Indigenous lady (E) making traditional chocolate ball shaped candies containing mushroom extracts (F, circles).

Fig. 6. Mushroom training workshops (A), and selling of diverse mushroom products made by Mico-Lógica Oaxaca at the traditional Mushroom Fair from Cuajimoloyas village (B-D), Northern Mountains from the State of Oaxaca, Mexico.

Fig. 7. The use of composted mushroom spent substrate for mulching vegetable parcels in the community of "Benito Juárez", State of Oaxaca, Mexico.

and cheap. Likewise, rodents are mainly controlled using mousetraps. A solution of water and lime is used for cleaning shoes at the entrance of production rooms. Despite all these measures, there are some problems of green mold contamination (*Trichoderma*), caused by anaerobic fermentation or inadequate steaming of the substrate. In this case, contaminated bags are discarded far away from the mushroom growing rooms. Overpopulation of insects at growing rooms can occasionally damage mushroom production.

Spent substrates are composted for six weeks, and then used by farmers of the community as organic fertilizer (fungicompost) for producing vegetables and flowers (**Fig. 7**). Spent substrates are also used for mulching vegetable parcels and flowerbeds, applied directly to fruit

trees and plant bases. It helps to maintain soil moisture, to avoid the growth of weeds, and to protect the soil from strong rains. The spent substrate from sawdust has sometimes been used as a supplement for the cultivation of oyster mushrooms, in a 5% proportion of the substrate mixture.

PROSPECTS

The effort of Mico-Lógica Oaxaca has been outstanding considering the limited rural conditions found at the community of Benito Juárez, such as poor telephone/internet access and economic support. However, this initiative has shown that consistent mushroom cultivation can effectively be promoted, even under such a difficult situation. Households from the community and surrounding villages are encouraged to develop mushroom cultivation as a private activity to obtain benefits, such as personal or family consumption and income. It is important that families show commitment for high quality and efficient mushroom production. Mushroom growers organized within a regional network to develop an increasing market for fresh and processed mushrooms, may become more viable. Previous reports have shown that traditional community organization in this region is well established[9]. A chopping machine has been acquired in this way, facilitating substrate preparation and storage (corn-cobs, cereal straws, leguminous stubble, *Agave* bagasse). Other equipment will also be bought for improving efficiency of all cultivation processes, including a laboratory for spawn production. A regional network is helpful for production planning according to environmental conditions. For example, building semi-open structures in the communities of Santa Martha Latuvi (Sierra de Juárez) and San Mateo Río Hondo (Sierra del Sur) for the cultivation of shiitake (*Lentinula edodes*) and enokitake (*Flammulina velutipes*), while the community of Tlacochahuaya (Oaxaca Valley, lower altitude) for the cultivation of reishi (*Ganoderma lucidum*). A financial analysis of mushroom cultivation under conditions described, considering variable (labor, consumables, materials, marketing) and fixed (electricity, energy, facilities and equipment wear and tear) costs, showed a profitable cost-benefit ratio of 2.07. This result confirmed previous work showing the sustainability of the model for rural production of edible and medicinal mushrooms in Mexico[5]. The cultivation of other species is in progress, such as the "wood blewit" [*Lepista nuda* (Bull.) Cooke], a gourmet mushroom species in Europe and widely consumed in communities of Mexico. The inoculation of mycorrhizal mushrooms (*e.g.*, *Boletus* spp.) for trees used in reforestation projects, and even log cultivation of bioluminescent mushrooms (*Panellus* and *Omphalotus*) as attraction for eco-touristic hiking areas, are also planned as part of the regional network of mushroom growers.

The rural production of edible and medicinal mushrooms has certainly good potential of expansion in the northern mountains from the State of Oaxaca, as well as in other regions of Mexico. There would be great benefits for local communities. Social benefits include greater mushroom consumption, local labor, decreased immigration. Ecological benefits involve the recycling of byproducts from agriculture and forestry, as well as ecological conservation). Main economic benefits are household incomes, and the promotion of eco-tourism. These benefits can even be further improved, if

suitable training, technical and economical supports are timely provided.

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