Chapter 1

Competitive Edible Mushroom Production from Nonconventional Waste Biomass

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.69071

Abstract

Worldwide, there is an increase in acreage dedicated to the competitive production of fruits, vegetables, flowers, and palms crops as productive diversification for food, feed, fiber, and fuels. However, in developing countries, there is malnutrition by an inadequate diet caused by deficiency in quality or quantity of food. Therefore, options are needed for the production of foods, mainly of high protein content such as edible mushroom from by-products. In Veracruz, Mexico, there is a large megadiversity of wastes derived from endemic plants, fruits, legumes, pods, leaves, straws, and flowers that are generated in a large amount and are disposed off through open-field burning without a specific use. The objective was to evaluate the potential of 30 nonconventional by-products and wastes for the production of low-cost oyster mushrooms *Pleurotus ostreatus.* Biological efficiency (BE) varied from 17.65 to 180% and at least the 60% of the evaluated substrates (BE greater than 50%) are viable for the production of mushroom *Pleurotus* especially in view of its low contamination in trials and abundance and availability and diversity throughout the agricultural year as wastes. Besides, the spent substrates were converted into organic manure compost, vermicompost and bocashi to close the cycle for new food production.

Keywords: protein-rich food, lignocellulosic by-products, competitive rural enterprises, oyster mushroom, organic manures

1. Introduction

1.1. Issues and constraints for the competitive and sustainable food production in Mexico

According to FAO estimates [1], 795 million people worldwide lack the quantity and quality of food needed to enjoy an active and healthy life. The vast majority live in developing regions. To better understand the problem, the concept of food and nutritional security defined by the Food and Agriculture Organization of the United Nations (FAO) has been established as "Physical and economic access to sufficient safe and nutritious food to meet their needs food preferences in order to lead an active and healthy life." This concept began to take on importance since the 1920s, with efforts to mitigate hunger; In the 1950s and 1960s, government actions were directed toward increasing the productivity and efficiency of marketing systems [2]. At the global level, this concept became more important as a result of the financial, energy and food crisis of 2008. Major advances have been made since the early 1970s in increasing food or raw material production, but this progress slowed down during the 1990s, due to factors such as climate change and climate change routing of crops for the production of biofuels.

In accordance with Urquía-Fernandez [3], food security is based on four elements: availability, access, food use, and stability of supply; to these, we must add two effects of an inadequate intake of foods that are obesity and malnutrition. That is why although in Mexico the average energy availability is 3145 kilocalories per person per day, 14% of the infant's present malnutrition, 30% of the adult population suffers obesity in different degrees and more than 18% of the total population is classified as food poverty by income. One of the reasons for this phenomenon is explained by the processes of development and sociocultural changes that are occurring in Mexico, which directly influence the eating patterns characterized mainly by a high intake of foods rich in cholesterol, saturated fats, sugars, and salts [4]. In addition [5], indicates that products oriented toward a more economical market usually have the highest content of fats, sugars, and additives. Poor nutrition has social and economic effects, a hungry person is not an efficient worker, they present more frequently illnesses and a poor nutrition of mothers has repercussions on children with lower physical and mental capacity [6, 7].

The current global capacity to produce food is such that the needs of all its inhabitants can be met. Numbers from the National Institute of Statistics, Geography, and Informatics (INEGI) indicate that there is sufficient food availability in Mexico [8]. FAO established an indicator called Food Energy Supply (SEA), defined as the daily consumption of food energy per person over a given period and including food produced or imported by countries for human consumption; for Mexico in 2000, this indicator has a value of 3159 kcal/day and its energy needs per person are calculated at 2182 kcal/day; therefore, the information indicated is validated. Unfortunately, there are factors that have limited adequate access to food by the population. These factors include transfer costs and the lack of price regulation of the basic food basket [9].

Currently in Mexico there is a very noticeable change in the dietary habits of the population, since the patterns of consumption have left their local and regional characteristics to gradually evolve to a standard national, that is to say the traditional Mexican food has succumbed to the search of the imitation of the food model of the developing countries. An example of this is the change in food with abundant cereals and legumes, a variety of fruits and vegetables and small portions of food of animal origin, which has been displaced by a diet based on products of animal origin with their corresponding intake of saturated fats and cholesterol, very refined cereals with low fiber content and high consumption of sugars and sweeteners. The product of these changes in diet is reflected in chronic diseases such as malnutrition, overweight, obesity, and diabetes [10].

Food is a physiological need characterized by food intake influenced by various factors such as culture, food, and economic availability, and environmental and family issues. The human metabolism needs to cover a daily requirement of approximately 50 nutrients to maintain their health, some of these nutrients are considered essential because the organism can not produce them, so it is necessary to ingest them in the daily diet [11]. There are studies that indicate that 90% of cases of malnutrition are caused by an inadequate diet, which can be caused by a deficiency in quality or quantity of food eaten [12]. Currently, in Mexico, it is estimated that 1.5 million children under 5 suffer from chronic malnutrition. As for overweight and obesity, this is caused by the abuse of high-calorie foods, with high concentrations of fats, salt, and sugars and with low amounts of vitamins, minerals and fiber, coupled with little or no physical activity; Genetic factors also contribute. In Mexico, 10% of children under 5 years of age and 70% of the economically active population present cases of overweight and obesity [13]. Diabetes, a disease considered the epidemic of the twenty-first century, since in 2007 its prevalence in Mexico was 7% [14].

The change of the patterns of feeding in Mexico has been given since the conquest with the introduction of new species of cattle and other species of cereals; however, some rural communities and certain sectors of the urban population maintain part of that pre-Hispanic food culture that is characterized by foods with great nutritional value. Before the Spanish conquest, the feeding of the different pre-Hispanic Mesoamerican cultures was based on a great diversity of animal and vegetal species peculiar to each of the geographic regions (both wild and domesticated). The availability of products used as food at this time was very varied; among them, we can mention edible plants, herbs and condiments, flowers, and fruits and highlight the use that was given to mushrooms named generically as nanácatl or forest fungus (**Table 1**). Estrada [15] points out that up to six names are registered in the Florentine Codex to refer to edible fungi. Pre-Hispanic cultures appreciated their great biological diversity and developed forms of sustainable use of their resources; One example of this is the multiple benefits they obtained from the main food of the indigenous peoples, maize: the sweet stalk was consumed directly, the leaves were used to wrap food like *tamales* where it served as protection during cooking, *elote* which is consumed directly desgrained or whole, from these grains are obtained *tortillas*, sweet *tamales* and drinks; Even pests of corn are exploited as are the worm (*gusano elotero*) and the fungus that infestated them called *cuitlacochin*. With the voyages of discovery and commercial exchanges with the world, many species were introduced and successfully adapted due to their use by indigenous groups, and many of these associated species survive to this day and constitute almost half of the dietary in México [16]. In the period 2000–2013, it is estimated that the Mexican population reduced their consumption of fruits and vegetables by 30% and consumed 40% more sweetened drinks and 10% more carbohydrates in their diet [7].

Common name	Náhuatl name	Scientific name
Calabaza	Ayutli	*Cucurbita pepo*
Bean	Etl	*Phaseolus* spp.
Chile	Tzilli	*Capsicum annum* y *C. frutescens*
Corn	Cintli	*Zea mayz*
Chayote	Chayutli	*Sechium edule*
Huazontle	Quauzontetl	*Chenopodium berlandieri* ssp. *nuttalliae*
Quelite	Quilitl	*Chenopodium album*
Quintonil	Quintonilli	*Amaranthus hybridus*
Purslane	Itzmiquilitl	*Portulaca oleracea*
Red tomato	Xitomatl	*Lycopersicum esculentum*
Green tomato	Tomatl	*Physalis philadelphica*
Nopal	Nopalli	*Opuntia* spp.
Vanilla	Tlilxochitl	*Vanilla planifolia*
Achiote	Acyotl	*Bixa orellana*
Chipilín	Chipilli	*Crotalaria longirostrata*
Epazote	Epazotl	*Chenopodium ambrosioides*
Colorín	Zompantle	*Erythrina* spp.
May flower	Cacaloxóchitl	*Plumeria* spp.
Izote	Iczotl	*Yucca elephantipes*
Custard apple	Zacualtzapotl	*Annona cherimola*
Chicozapote	Xicotzapotl	*Manilkara zapota*
Guava	Xalococotl	*Psidium guajava*
Tejocote	Texocotl	*Crataegus mexicana*
Capulín	Capolin	*Prunus serotina*
Nanche	Nantzinxocotl	*Byrsonima crassifolia*

Table 1. Pre-hispanic food consumed in some regions of Mexico [15].

The agricultural systems in México have been oriented to intensive production characterized by various factors such as the implementation of technologies to increase productivity, an adaptation of crops to the demands of international markets and genetic modifications to improve product varieties. In addition, government support has been received with the aim of promoting the productive reconversion and diversification of traditional crops. Besides, irrigation is poor; therefore, Mexican agriculture is still mostly rainfed and highly affected by climatic variations (**Figure 1**).

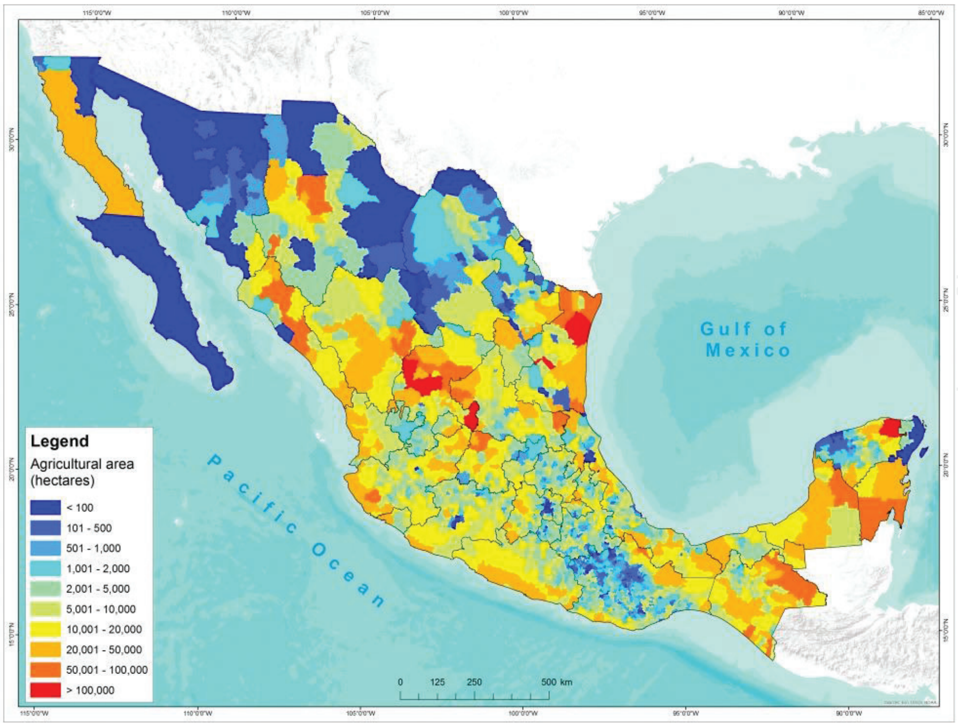

Figure 1. Rainfed agriculture in Mexico [8].

Agricultural activities produce significant amounts of waste (**Table 2**) and by-products that can be used in the formulation of animal feed, edible mushroom and in the production of compost and vermicompost, techniques that consist in the degradation of organic matter by the action of microorganisms and worms respectively, to produce humus or organic manure, products that increase the availability of plant elements [17]. Unfortunately, it is estimated that only 50% of the total produced is used. The burning of agricultural waste is a widespread practice in Mexico to dispose of or reduce the volume of agricultural products, and it is an economical and easy practice. According to conclusions published by CEC [18], it is estimated that biomass burning "Produces 40% of carbon dioxide (CO2), 32% of carbon monoxide (CO), 20% of particulate matter or (PM) and 50% of polycyclic aromatic hydrocarbons (PAHs) emitted to the environment on a global scale." A very important alternative for the use of agricultural residues is the use of biotechnology that allows the establishment of solid state fermentation of fibrous residues in the production of edible mushroom and later from their waste, animal feed and compost.

Taking as reference the report of the global condition of agriculture and food [20] and based on projections of population growth, world food demand in 2050 is expected to be at least 60% higher than 2006. Taking this stage into account, it is necessary to develop processes that are orientated toward sustainable food production. On the one hand, adequate food must be ensured for future generations, and on the other hand, these processes should no longer affect natural ecosystems and their ecological services; we must even go beyond restoring and creating the natural resources that have been damaged.

Crop	Generation coefficient
	(t residue/t product)
Wheat	1.20
Barley	1.35
Oats	1.35
Rye	1.35
Corn	2.00
Rice	1.50
Sorghum	1.70
Citrus fruits	0.15
Sunflower	2.00
Cotton	2.00
Sugar cane	1.50

Table 2. Biomass generation coefficient in different crops [19].

2. Potential for competitive food cultivation from biodiversity in Veracruz, Mexico

Veracruz State is a crescent-shaped strip of land located in Eastern Mexico wedged between the Sierra Madre Oriental to the west and the Gulf of Mexico to the east. Its total area is 78,815 km^2. It extends about 650 km north to south but its width varies from 212 to 36 km. Even when the elevation of a great portion of the State is between sea level to one thousand meters, the topography in the west in some areas changes drastically, creating a complex system of mountains and valleys which can reach altitudes over five thousand meters.

The combination of these factors generates an interesting mosaic of climatic conditions according to the methodology of Ref. [21]. In Veracruz, annual mean temperature goes from almost 27°C (81°F) to −1°C (30°F). The lowlands located in the south are relatively warmer than the lowlands in the north. In contrast, the central portion of the State has temperatures that can reach 0°C in the highest mountains. Annual precipitations show too a great variation. Even when about 40% of the territory has precipitations between 1000 and 2000 mm, in some western areas, yearly rainfall is below 500 mm. In the other extreme is possible found regions where the annual rainfall is over three thousand mm (reaching a maximum of 3230 mm). The distance to the coastline, the elevation range, and the physiographic conditions also generates enormous variations in moisture, temperature annual range, and temperature seasonality besides the variations in the distribution of rainfall. The environmental conditions present the Veracruz permit the existence of different biomes (**Figure 2**).

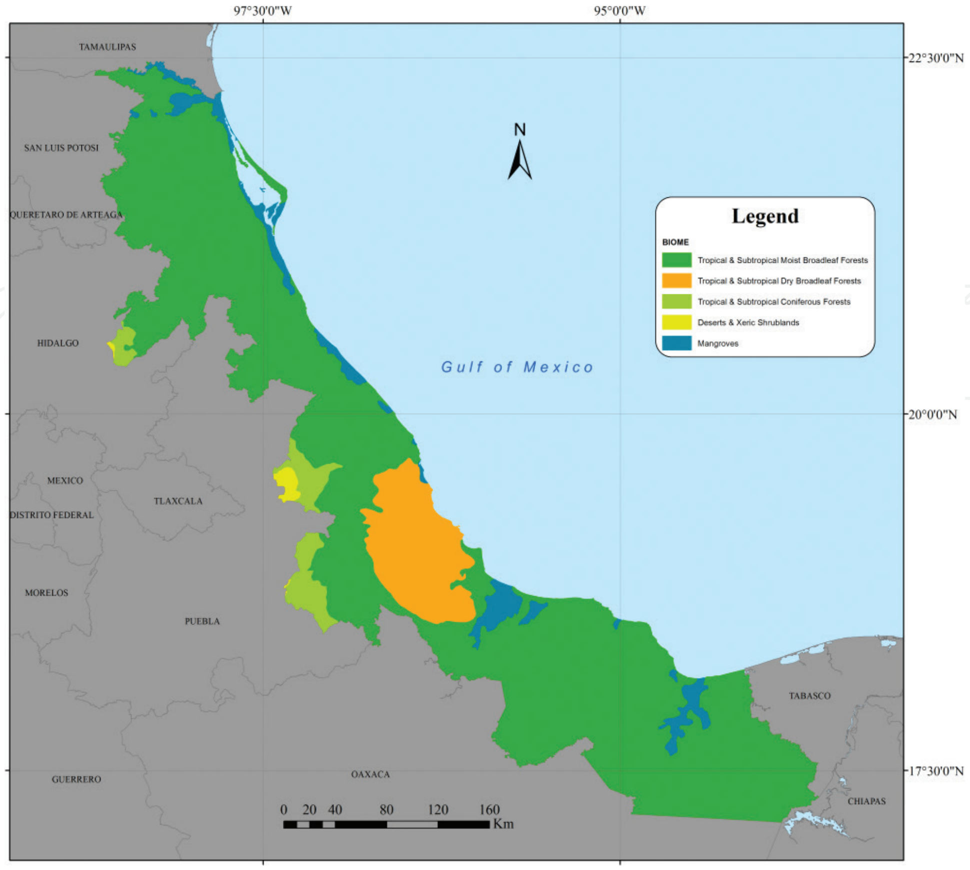

Figure 2. Biomes in Veracruz.

Although tropical & subtropical moist broadleaf forest occupies a great portion of the State, tropical and subtropical dry broadleaf forest, tropical and subtropical coniferous forest, xeric scrubland, and mangroves are present too. Consequently, the biodiversity existing in the territory is one of the greatest in the country. Current data indicates that native vascular plants species are over 5472 species, i.e. 28% of the total number of species present in Mexico and 2% of the vascular plants that exists in the world.

The climatic mosaic present the Veracruz combined with the edaphic variability also had allowed the cultivation of a great variety of native and exotic crops (from annual herbaceous to tropical and subtropical tree species), which found the appropriated conditions to grow adequately. As a result of the distribution of mountain ranges in Veracruz and their latitudinal positions each region on the state has contrasting soil types, climatic, hydrologic, and biotic characteristics (**Table 3** and **Figures 3–5**).

However, despite the high potential for the production of various crops, Veracruz is the third state in Mexico with the highest level of poverty, therefore, alternative food production required to complement traditional systems of food production and transit to sustainability.

Major soil group	Characteristics	%
Acrisols	Soils with subsurface accumulation of low activity clays and low base saturation	8.5
Cambisols	Weakly to moderately developed soils	7.0
Rendzinas	Dark soils rich in organic matter over calcareous material	4.4
Gleysols	Soils with permanent or temporary wetness near the surface	5.1
Phaeozems	Soils with a thick, dark topsoil rich in organic matter and evidence of removal of carbonates	12.5
Lithosols	Azonal soil consisting chiefly of unweathered or partly weathered rock fragments	2.5
Fluvisols	Young soils in alluvial deposits	0.4
Kastanozems	Soils with a thick, dark brown topsoil, rich in organic matter and a calcareous or gypsum-rich subsoil	0.2
Luvisols	Soils with subsurface accumulation of high activity clays and high base saturation	9.6
Nitosols	Soils with shiny surfaces on structural faces (peds) of the soil	0.5
Arenosols	Sandy soils featuring very weak or no soil development	1.4
Regosols	Soils with very limited soil development	14.8
Andosols	Young soils formed from volcanic deposits	5.8
Vertisols	Dark-coloured cracking and swelling clays	25.5
Planosols	Soils with a bleached, temporarily water-saturated topsoil on a slowly permeable subsoil	0.2
Solonchaks	Strongly saline soils	0.2
Others		1.4

Table 3. Soil types from Veracruz [22].

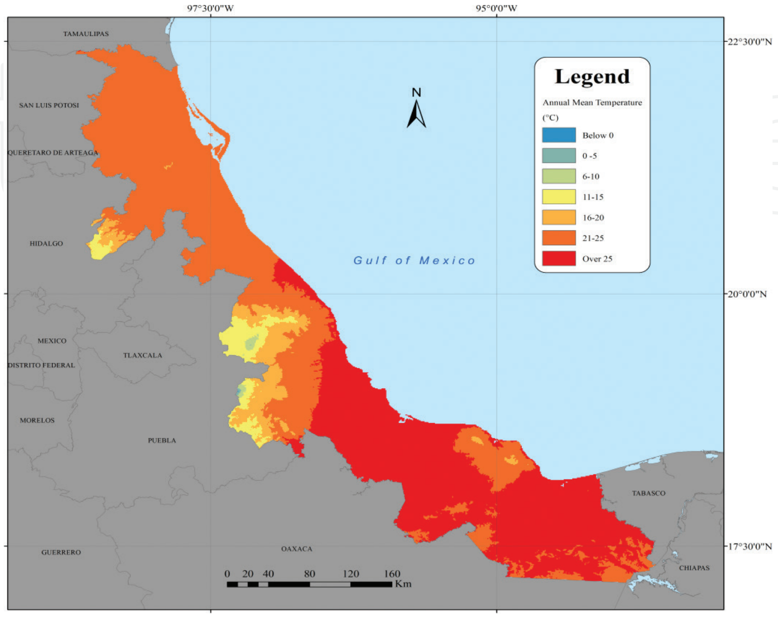

Figure 3. Average temperatures in Veracruz.

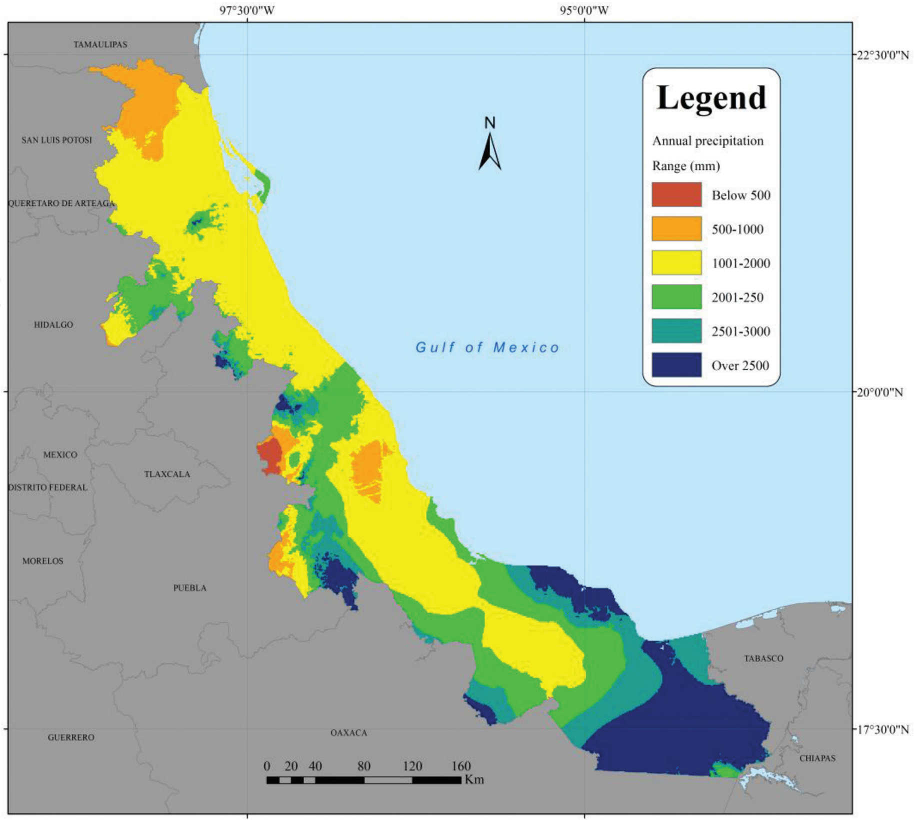

Figure 4. Annual precipitation in Veracruz.

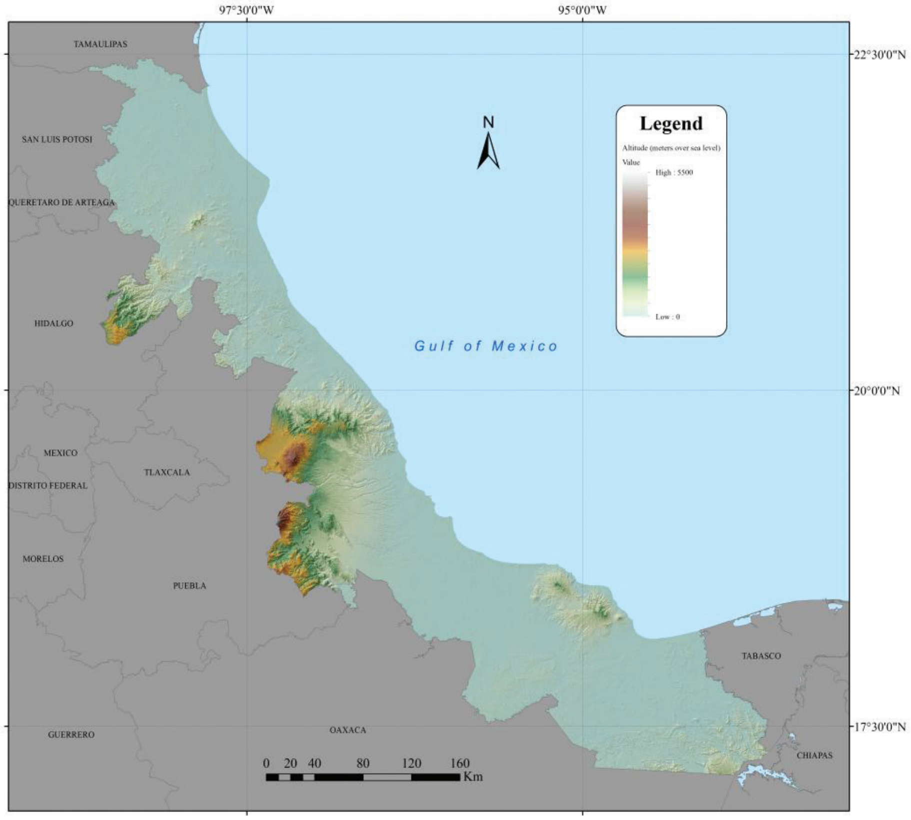

Figure 5. Slopes in Veracruz.

3. Nonconventional by-products and waste biomass from Veracruz for *Pleurotus* cultivation

Pleurotus species represent a well-defined group of Basidiomyceteous fungi of the order Agaricales and family Tricholomataceae. They are characterized by the production of fruit bodies with an eccentric stalk and a wide cap shaped like an oyster shell, with the widest portion of the cap being away from the stalk. They grow over a wide range of temperature and are able to colonize a wide spectrum of unfermented, natural, lignino-cellulosic wastes. Because of their fast mycelial growth rate, they colonize the substrates rapidly; the yield of fruit bodies is also high [23]. Worldwide the production of edible mushroom is widely distributed; however, in Mexico, it is still poor (**Figures 6** and **7**)

The importance on the research for *Pleurotus* cultivation is the alternative to transform a wide range of organic wastes to nutritional protein food with easy access and low cost in Veracruz Mexico[26]. There are many reviews analyze the *Pleurotus* production on different substrates [27–31]. In this study, we assessed the mushroom production on 30 nonconventional agricultural by-products and agro-industrial wastes and some combinations for the cultivation of *Pleurotus*. We used a commercial strain of *Pleurotus ostreatus* supplied by a supplier national laboratory. The wastes biomass was collected from the main crops representative from different regions in Veracruz. The preparation of substrates were completely dried under the sun, chopped, washed, soaking in cold water and sterilized by immersion in hot water (80°C) during 1 h; later when substrate was at room temperature, it was inoculated into bags or plastic container with 2.85 kg of substrate (wet weight) and 0.150 kg of spawn (5%). The incubation was in darkness condition at room temperature, when the primordium was observed the bags were transfer to a production room with conditions recommended by literature [32–34]. We presented a diversity of substrates for *Pleurotus* production from agricultural wastes in Veracruz, and some of these are reported as the first time for its cultivation. The control substrate was old corrugated container (OCC) (**Figures 8** and **9**)

According to the substrate, we observed a large variability on mushrooms production. The biological efficiency (BE) varies from 17.6% (Chilean pine leaves) to 180% (Pineapple fiber and

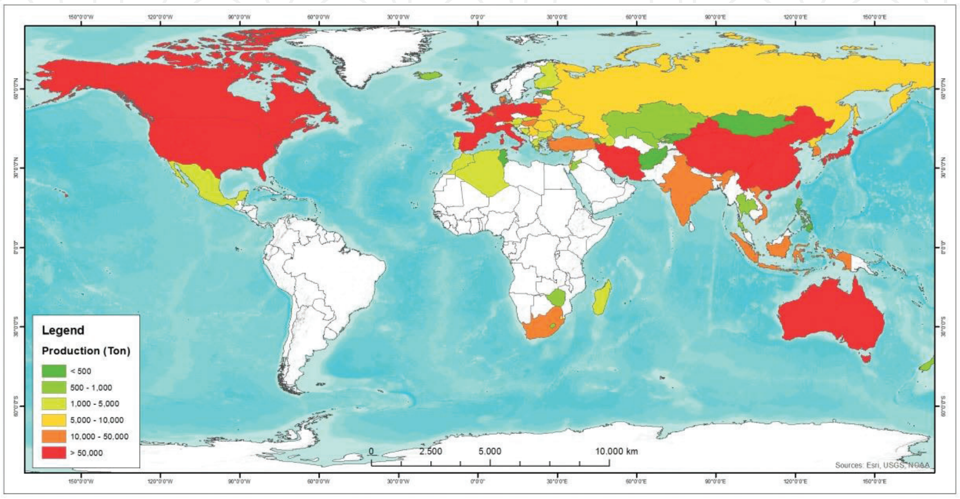

Figure 6. Edible mushroom world production [24].

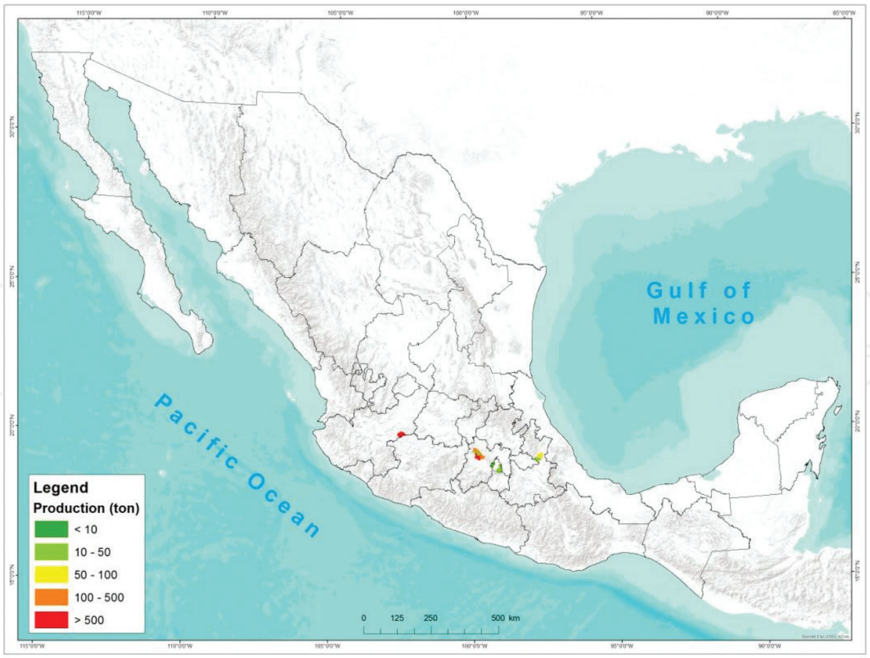

Figure 7. Edible mushroom production in Mexico [25].

Leucaena leucocephala
Chamaedorea tepejilote
Tillandsia usneoides
Erythrina americana Miller
Pods of bean
Shells and coconut fiber
Pineapple fiber
Corn cob
Maize flowers
Agave fiber
Araucaria araucana
Chayote (*Sechium edule*)
(*Persea schiedeana Nees*) leaves
Bagasse of trapiche
Sugarcane flower
(*Mangifera indica*) leaves
Queen palm (*Syagrus romanzoffiana*)
(*Pinus patula*) needles
Cymbopogon citratus
Pith

Figure 8. Some wastes as substrates used in the production of *Pleurotus* edible mushroom.

Spawning Fructification Harvesting

Figure 9. Stages of the edible mushroom production.

pods of guaje), more than 60% of substrates presented a biological efficiency (BE) equal or higher than 50%. Nevertheless, the evaluated period vary from 20 to 96 days (steam of garlic, sugar cane tops, and OCC, respectively), affecting enormously the production rate (PR) from 0.7 to 5.8 and physical characteristics of the final product (**Table 4** and **Figures 10** and **11**).

Substrate	BE(%)	Days of treatment	Production rate	Yield
Chilean pine leaves (*Araucaria araucana*)	17.65	23	0.77	5.61
Tropical wood sawdust	25.00	28	0.89	6.17
(*Pinus patula*) needles	33.33	24	1.39	8.47
Queen palm leaves (*Syagrus romanzoffiana*)	34.62	26	1.33	6.25
Agave fiber	35.00	27	1.30	7.07
(*Mangifera indica*) leaves	35.71	24	1.49	9.62
Sugarcane pith	40.00	23	1.74	8.89
(*Yucca elephantipe*) leaves	45.00	25	1.80	8.65
(*Tillandsia usneoides*) Pascle	46.15	21	2.20	7.59
Cempasuschil (*Tagetes erecta*) stalks	50.00	22	2.27	12.50
Stem of garlic	50.00	20	2.50	10.34
Maize flower	50.00	27	1.85	8.77
Sugar cane flower	55.00	22	2.50	9.91
Lemongrass (*Cymbopogon citratus)*	58.33	26	2.24	8.64
Shells and coconut fiber	59.00	84	0.70	12.29
Corn cob	61.67	28	2.20	15.42
(*Persea schiedeana* Nees) leaves	62.50	23	2.72	8.47
Banana wastes	65.00	25	2.60	12.04
(*Chamaedorea tepejilote* Liebm) leaves	72.22	23	3.14	11.30
Stem of onion	84.62	21	4.03	12.50

Substrate	BE(%)	Days of treatment	Production rate	Yield
Tomato straw	90.00	42	2.14	15.00
Bagasse from trapiche	100.00	26	3.85	13.51
Sugarcane tops	120.00	85	1.41	31.76
Pea pods (*Pisum sativum*)	125.00	25	5.00	24.04
(*Erythrina americana* Miller) flowers	135.0	23	5.87	22.69
Pods of bean	142.5	60	2.38	67.86
Chayote (*Sechium edule*) straw	150.0	40	3.75	16.67
Pineapple fiber	180.0	54	3.33	90.00
Pods of guaje (*L. leucocephala*)	180.0	53	3.40	90.00
Old corrugated container (OCC)	48	96	0.5	12.88

BE: Biological efficiency (fresh mushroom weight/dry substrate weight); Days of treatment: Days from inoculation until the last harvest; Production rate: BE/days of treatment; Yield: fresh mushroom weight/fresh substrate weight.

Table 4. By-products and waste biomass from Veracruz evaluated for *Pleurotus* cultivation.

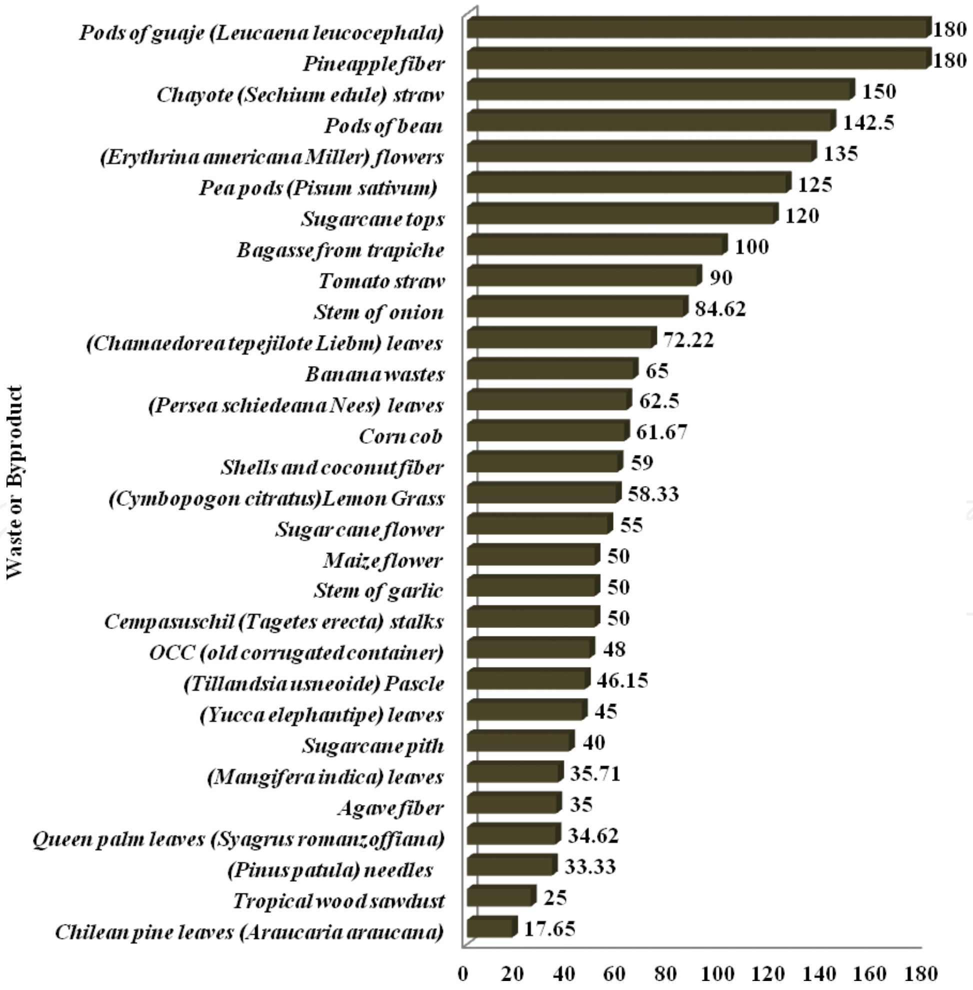

Figure 10. Biological efficiency (BE%) of substrates (Experimental data).

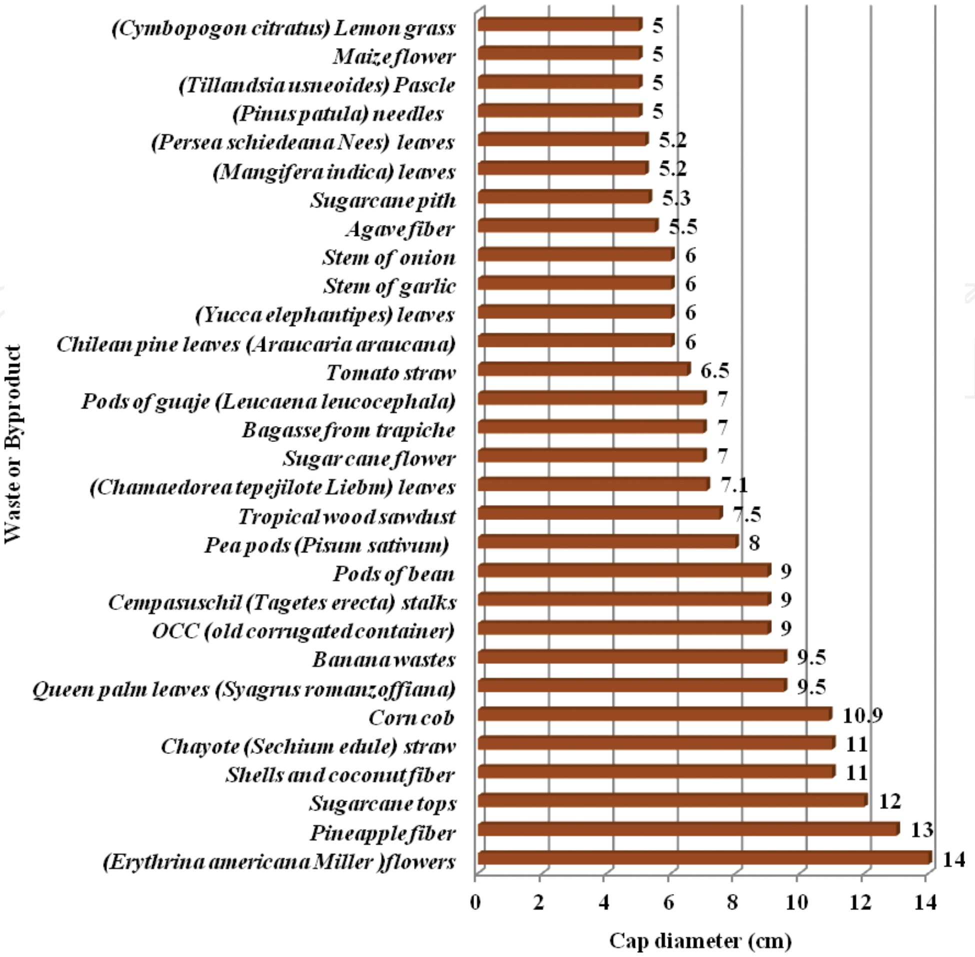

Figure 11. Physical characteristics of produced edible mushroom (Experimental data).

4. Potential of substrates for *Pleurotus* production

The highest BE were observed on the pods of guaje (*Leucaena leucocephala*) and pineapple fiber, both with 180%. Our results are consistent with a recent report of *L. leucocephala* for *P. ostreatus* cultivation, which obtains 157% of BE [35]. They have observed an increase in the nutritional value of sporophores; however, in another study, when *L. leucocephala* is mixed with rice straw [36], the BE has been 65%. In the case of the Pineapple fiber as a substrate, there exist few reports with the objective to obtain fructification of *Pleurotus*. One study [37] reported a BE of 103% with *P. ostreatus*, but on the other hand, however [38, 39] proved that the wastes from this plant stimulate the enzyme of *Pleurotus*, particularly important to obtain by-products. These two substrates represent an excellent choice to obtain a high biomass production for *P. ostreatus* in Veracruz.

Beyond the BE, is important to consider the time to production, because a rapid spawn run would reduce the time noncolonized substrate when it is exposed to competitors such as weed mold and bacteria, this affect the cost production and the risk of contamination. In this study, we consider the production rate (PR) as the division between BE on the days to production. Interestingly was the case of Bean, guaje (*L. leucocephala*) and legume pods mix with a BE of 125% and PR 5.0 and *Erythrina americana* flowers with a BE of 125% and 5.87 of PR, the evaluated period for production was the 25 and 23 days respectively. The first substrate includes the *L. leucocephala,* it is well known to have a high content of Nitrogen [40, 41], and this can help to supply the nutrition of *Pleurotus* to increase the biomasse as mentioned earlier. This is the first report of the *Erythrina americana* flowers, used as a substrate for *Pleurotus* cultivation. This flower is an edible flower from wild plants consumed in some areas in Mexico. In Veracruz, it is consumed during a short time of the season when they are blooming, generally in February, March, and April [42, 43]. Currently, there has not a commercial use of this flower, then to collect and stock this waste during this season could be a strategy for *Pleurotus* cultivation during the year.

On the other hand, the most part of substrates presented a BE higher than 40% and a PR higher than 1 (except the Shells and coconut fiber), these are Sugarcane pith, *Yucca elephantipes* leaves, *Tillandsia usneoides*, *Tagetes erecta* stalks, Stem of garlic, Sugar cane flower, *Cymbopogon citratus*, Corn cob, *Persea schiedeana* Nees leaves, Banana wastes, *Chamaedorea tepejilote* Liebm, Stem of onion, Tomato straw, Bagasse from trapiche and Sugarcane tops. From those, the

Pith sugar cane [44, 45], Yucca [46], steam of garlic [47, 48], *Cymbopogon citrates* [49], corn cob [30, 35, 47, 49] and Banana wastes [35, 50–52], Onion [53] (stimulation of enzymes of *Pleurotus*), Tomato straw [36, 54], and Pod of beans [49] have been reported, but this is the first report for *Tillandsia usneoides, Tagetes erecta* stalks, Sugar cane flower and *Persea schiedeana* Nees leaves and Chamaedorea tepejilote Liebm leaves as substrates for the *Pleurotus* cultivation. All these substrates represent an economical opportunity, as is reported for *Pleurotus* that a minimum of 40% of BE is economically viable [55]. From these substrates, the banana wastes have been reported as a good option to produces *P. ostreatus* [35, 51, 56], and recently reported that it can increase the lacassa activity of vegetative phase of *P. ostreatus* [57]. Therefore, we consider the banana waste is interesting substrates to develop a standard process for cultivation of *Pleurotus*.

5. Sugar cane by-products

It is particularly important the case of the by-products and wastes of sugar cane. In this study, we use four by-products from this crop: sugarcane pith (40% BE), sugar cane flower (55% BE), bagasse from trapiche (100% BE), and sugarcane tops (120% BE), all of them with an important result for production. Veracruz is the highest producer of sugar cane in Mexico [58], (**Figure 12**) there are big amounts of by-product without a specific use, this should be one of the main substrates for *Pleurotus* production in this state, and this allow to obtain a large amounts of substrate, from short distance and at low price. There are several reports about the use different by-products from sugar cane as substrates for *Pleurotus* cultivation with interesting results for yield [59–63]. This is a no profited by-product with a high potential to transform wastes to nutritional biomass for the economic development.

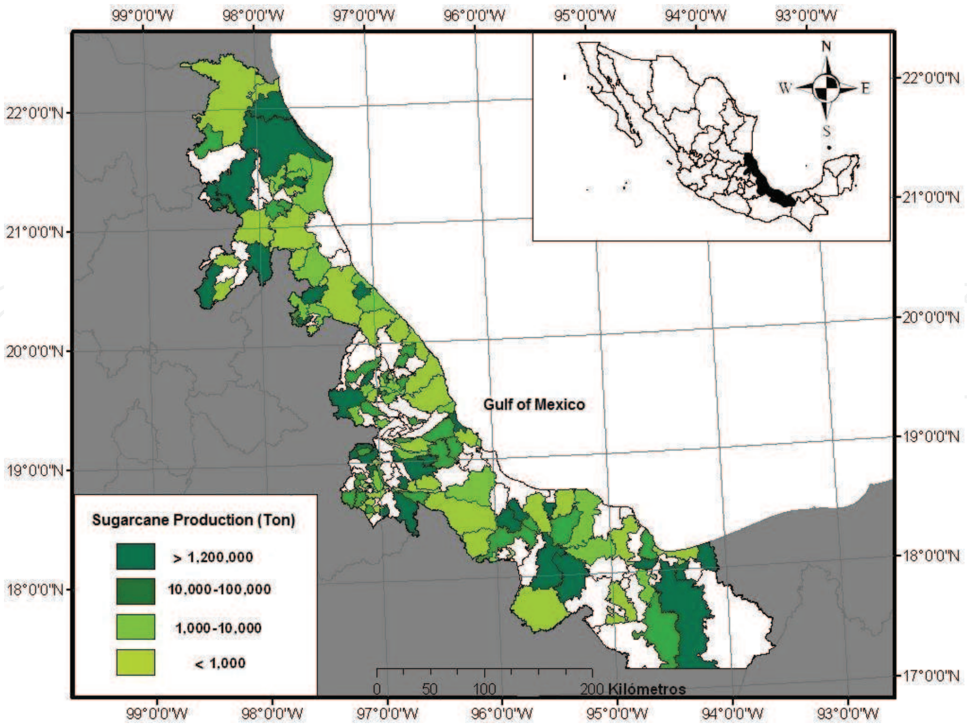

Figure 12. Sugarcane production in Veracruz Mexico [25].

6. Diversity of substrates during the year

In general, the importance of all these substrates here presented is that there are available on different seasons during the year; the price is usually is very low or even for free, thus this is the opportunity to develop a plan production to use specific substrates during the year. Verma [64]analyze an economic model for a farm for *Pleurotus* cultivation based on coffee pulp on México, which could be improved by the adding the sugar cane wastes and other agricultural by-products mentioned earlier.

The high prices of raw materials used as substrates for the mushroom cultivation could increase the cost of commercial production (*P. ostreatus*). In Mexico, the wheat straw and barley straw are the most common substrates for cultivation of *Pleurotus* [64, 65], while the 77% of this crops is produced in Sonora y Baja California, and the by-products come from the northern of Mexico [66, 67], and their availability vary during the year and as the same as the price. Nowadays, there is some sugar mill research for different use for bagasse, which subsequently may avoid ecological problems as pests and lixiviation produced by the accumulation of big amounts of wastes, this process is also necessary to avoid ecological problems as pests and lixiviation produced by the accumulation of big amounts of wastes. It is an opportunity to develop a plan including the mix of the most important wastes from this region for plan *Pleurotus* cultivation and other tropical edible mushrooms.

Into the plan, is important consider some characteristics of the substrates, according to [59], the materials used for substrates of *Pleurotus* should count with positives properties as (1) availability of amount and time, (2) knowledge of their physic-chemical content, (3) stability on their physic-chemical content, (4) advantage on cost, (5) easy location on short distance and (6) easy to transport. For some substrates here presented, is important to consider the points two and 3, being that is the first reports for *Pleurotus* cultivation, and then more studies are necessaries to guaranty the safety on the long term.

7. Composting edible mushroom wastes

In order to reuse the spent substrates from the production of edible mushroom *P. ostreatus*, compost production was exclusively used grass pruning residue, unlike other conventional inputs such as sugar industry byproducts (filter mud, bagasse, and vinasses) or cattle manures used in composting. The materials used once weighed were placed on a layered plastic to form a static pile with a rectangular pyramidal structure: The layers were formed with fresh grass, edible mushroom waste and covered with fresh grass until exhausted the substrates to complement 40 kg of fresh grass and 40 kg of edible mushroom waste.

The grass was used as the initiator of the microbial growth process to reach the thermophilic phase temperatures indispensable in composting. The initial moisture content of the grass was 82% and for waste edible mushroom 25%, so water was added so that the moisture of the pile formed was 75%. During the experimental process, the pile moisture remained in the 65–70% range [68, 69]. The figure details the dimensions of the pile made with the previously mentioned substrates (**Figure 13**).

The composting process can be considered as an effective method to transform organic matter from edible mushroom production into a potentially safe, stable and harmless material that can be used as a soil improver, organic fertilizer, or manure substitute in crop soils (Chen et al., 2014). In the case of composting edible mushroom production wastes, the maximum temperature reached was 50°C, and this is attributed to the fact that the substrates were partially degraded by the mushroom growth process, thereby reducing a number of nutrients available in it.

At the same time, vermicompost and bocashi were obtained with edible mushroom production wastes which in turn was mixed with by-products from sugar and livestock industry by the conventional methods according to [70, 71] and evaluated for their nutritional value according to Mexican standard [72] (**Table 5**).

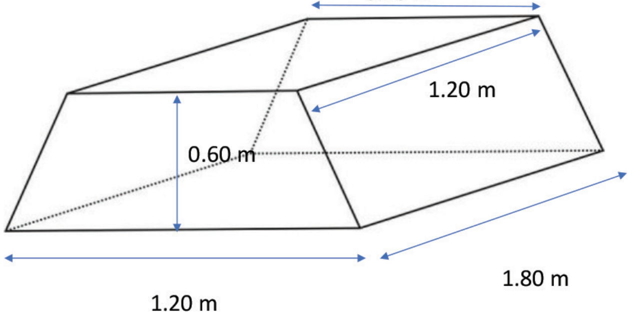

Figure 13. Composting static pile.

Variable	Unit	Compost[*]	Vermicompost[**]	Bocashi[***]
Humidity	%	49.31	48.98	44.77
pH		7.54	7.27	8.99
Soil electrical conductivity	dsm^{-1}	4.080	1.076	3.77
Ash	%	29.9	50.01	50.52
Organic matter	%	70.02	49.99	49.48
Total carbon C	%	40.615	28.996	28.701
Total nitrogen N	%	1.51	0.51	0.9
C/N		26.90	56.85	31.89
Ca	%	3.339	4.849	25.233
Mg	%	0.576	0.610	0.703
Na	%	0.102	0.029	0.619
K_2O	%	1.65	0.156	1.216
P_2O_5	%	1.258	3.711	1.071
Fe	%	0.0283	0.7310	0.1515
Cu	%	0.0018	0.0051	0.0024
Zn	%	0.0170	0.0324	0.0147
Mn	%	0.0377	0.1950	0.0715

[*] Compost from waste from cultivation of oyster mushrooms and grass pruning residue.

[**] Filter mud vermicompost and waste from cultivation of oyster mushrooms.

[***] Filter mud, cattle manure, ashes, lime and waste from cultivation of oyster mushrooms.

Table 5. Chemical composition of organic manures from edible mushroom wastes.

The content of organic matter in the compost at the end of the process indicates that once it is applied in the soil, it will continue with the degradation process, the nitrogen present indicates that during the cultivation of mushroom there was a significant consumption of the same. However, unlike the vermicompost and bocashi, the edible mushroom waste compost, obtained by the pile method, presents a neutral pH, higher carbon content, organic matter, and potassium and lower C/N ratio.

The final mass obtained was 10 kg, with a yield of 12.5%. (**Figure 14**) Composting of edible mushroom production wastes can be a technology of production of foods such as vegetables and organic manures at the same time; besides to manage the organic fraction of biomass in developing countries due to the simplicity and speed of implementation. This technology implies low costs in its application, compared to other processes, which require a strong investment for the installation, management, and operation of the necessary equipment [73].

Figure 14. Compost of edible mushroom wastes (Pile method) [Experimental data].

8. Conclusions

We presented the results of an evaluation of 30 nonconventional by-products and waste biomass and mixtures useful for *Pleurotus* cultivation. From those substrates, 23 of them showed a BE higher than 40%, that represent a minimum to be considered as economically viable. Seven of these substrates are reported as the first time for *Pleurotus* cultivation; however, more studies are necessary to know the physic-chemical properties, characteristics, and the stability for the production of *Pleurotus* in the long term.

The sugar cane represents one of the most important resources, being that Veracruz is the main producer of this crop in Mexico, and this opens the possibility to obtain a large amount of substrate for *Pleurotus*, in a short distance and at a low price.

It is important to develop a plan including the substrates analyzed to propose an economic plan for *Pleurotus* production and composting of waste substrates based on the local crops according to the season and region. It will allow to minimize cost for acquisition and transport of substrates for *Pleurotus* production as well as to avoid the accumulation of large amount of substrates that can produce pollution by pests and lixiviation improving with this closed cycle technology the competitiveness and sustainability of food production.

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References

[1] FAO. The State of Food Insecurity in the World 2015. Fulfillment of the international objectives for 2015 in relation to hunger: Balance of the uneven progress. Food and Agriculture Organization of the United Nations. Roma. 2015. Available from: http://www.fao.org/hunger/en/[Accessed: March 1, 2017]

[2] Soria SG, Palacio MVH. The actual scene of de feeding in México. [Internet]. 2014. Available from: http://www.academia.edu/12893339/The_Actual_Scene_of_the_Feeding_in_Mexico. [Accessed: February 11, 2017]

[3] Urquía-Fernández N. Food security in México. Mexican Public Health. 2014;**56**(1):592-598

[4] Fausto GJ, Valdez L RM, Aldrete RMG, López ZMC. Social historical antecedents of obesity in Mexico. Health Research. 2006;**VIII**(2):91-94

[5] Aguirre P. Socioanthropological Aspects of Obesity in Poverty. In: Peña M, Bacallao J. (Comp.). Obesity and Poverty: A New Public Health Challenge. Scientific Publication. Pan-American Health Organization; 2000;**576**:11-22

[6] FAO. Program to Fight Hunger. Dual Component Approach to Hunger Reduction: Priorities for Action at the National and International Levels. [Internet]. 2003a Available from: ftp://ftp.fao.org/docrep/fao/006/j0563e/j0563e00.pdf [Accessed: March 12, 2017]

[7] Román S, Ojeda-Granados C, Panduro A. Genetics and food evolution of the population in Mexico. Journal of Endocrinology and Nutrition. 2013;**21**(1):42-45

[8] INEGI. Sociodemographic Indicators of Mexico (1930-2000). [Internet]. 2001 Available from: http://internet.contenidos.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvinegi/productos/integracion/pais/mexvista/mexatg.pdf [Accessed: March 12, 2017]

[9] FAO. Nutrition Profiles by Country—Mexico. Food and Agriculture Organization of the United Nations. Roma. [Internet]. 2003. Available from: http://www.fao.org/countryprofiles/index/en/?iso3=MEX [Accessed: March 10, 2017]

[10] Ibarra-Sánchez LS, Viveros-Ibarra LS, González-Bernal V, Hernández-Guerrero F. Mexico Food Transition. Razón y Palabra. 2017;**20**:166-182

[11] Rivera JA, Pedraza LS, Aburto TC, Batis C, Sánchez-Pimienta TG, González de Cosío T, López-Olmedo N, Pedroza-Tobías A. Overview of the dietary intakes of the Mexican population: Results from the National Health and Nutrition Survey 2012. The Journal of nutrition. 2016;**146**(9):1851S-1855S.

[12] Gómez F. Malnutrition. Public Health of Mexico. 2003;45(4):s576-s582

[13] Shamah LT, Amaya CMA, Cuevas NL. Malnutrition and Obesity: Double Burden in Mexico. [Internet]. 2015. Available from: http://www.revista.unam.mx/vol.16/num5/art34/[Accessed: March 12, 2017]

[14] Hernández-Ávila M, Gutiérrez JP, Reynoso-Noverón N. Diabetes mellitus in Mexico. The state of the epidemic. Public Health in Mexico. 2013;**55**(2):s129-s136

[15] Estrada ME, Aguirre RJR. Feeding the old Mexicans. In: Sánchez VA. (Comp.). The Destruction of Indias and its Renewable Resources 1492-1992. México: UACh, Chapingo; 1999, pp. 141-152

[16] Sarukhán J, Koleff P, Carabias J, Soberón J, Dirzo R, Llorente-Bousquets J, Halfter G, González R, March I, Mohar A, Anta S, de la Maza J. Natural capital of Mexico. Synthesis: current knowledge, evaluation and sustainability perspectives. National Commission for the Knowledge and Use of Biodiversity. México. 2009. CONABIO, p. 100

[17] de Moraes Sá JC, Lal R, Cerri CC, Lorenz K, Hungria M, de Faccio CarvalhoPC. Low-carbon agriculture in South America to mitigate global climate change and advance food security. Environment International. 2017;**98**:102-112

[18] CEC. Burning Agricultural Waste: A Source of Dioxins.Montreal, Canada: Commission for Environmental Cooperation; 2014. p. 6

[19] Koopmans A, Koppejan J. Agricultural and Forest Residues-generation, Utilization and Availability. 1997. Available from: http://www.fao.org/docrep/006/AD576E/ad576e00.pdf [Accessed: March 12, 2017]

[20] FAO. The State of Food and Agriculture. Climate Change, Agriculture and Food Security. Roma, Italia. 2016. Available from: http://www.fao.org/3/a-i6030e.pdf [Accessed: February 28, 2017]

[21] Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GVN, Underwood EC, D'Amico JA, Itoua I., Strand HE, Morrison JC, Loucks CJ, Allnutt TF, Ricketts TH, Kura Y, Lamoreux JF, Wettengel WW, Hedao P, Kassem KR. Terrestrial ecoregions of the world: A new map of life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. BioScience, 2001;**51**(11): 933-938

[22] Galindo-Tovar ME, Aguilar-Rivera N, Gámez Pastrana MR, Leyva-Ovalle OR, Murguía-González J. 2015. Advances in Research on Tropical Horticulture in Sugarcane Crop Fields from Veracruz, Mexico. Ebook Series: Agricultural Research Updates. Available from https://www.novapublishers.com/catalog/product_info.php?products_id=55152&osCsid=a747dcf19b64b3288b2ad5b14afe591f.[Accessed: March 10, 2017]

[23] Rajarathnam S, Bano Z. *Pleurotus* mushrooms. 1A. Morphology, life cycle, taxonomy, breeding, and cultivation. CRC Critical Reviews in Food Science and Nutrition. 1987;**26**(2):157-223

[24] FAOSTAT. 2016. Available from http://www.fao.org/faostat/en/#data/QC [Accessed: March 12, 2017]

[25] SIAP. Anuario Estadístico de la Producción Agrícola. Available from: http://infosiap.siap.gob.mx/aagricola_siap_gb/icultivo/index.jsp>[Accessed: January 25, 2017]

[26] Chang S. World production of cultivated edible and medicinal mushrooms in 1997 with emphasis on Lentinus edodes (Berk.) Sing, in China. International Journal of Medicinal Mushrooms. 1999;**1**:291-300

[27] Pineda-Insuasti JA, Ramos-Sánchez LB, Soto-Arroyave CP, Ciudadela AA EP, Victoria L, Ecuador I. Producción de *Pleurotus ostreatus* por fermentación en estado sólido: una revisión. ICIDCA. Sobre los Derivados de la Caña de Azúcar. 2014;**48**:13-23

[28] Josephine RM. A review on oyster mushroom (*Pleurotus* spp). International Journal of Advanced Biotechnology and Research. 2014;**1**:7-9

[29] Díaz C, Carvajal R. Biological efficiency of *Pleurotus ostreatus* cultivated in palm fiber oil. @Limentech Ciência e Tecnologia de Alimentos. 2014;**12**:63-70

[30] De Carvalho CSM, Sales-Campos C, De Andrade MCN. Mushrooms of the *Pleurotus* genus: A review of cultivation techniques. Interciencia. 2010;**35**:177-182

[31] Rajarathnam S, Bano Z, Miles PG. *Pleurotus* mushrooms. Part I A. morphology, life cycle, taxonomy, breeding, and cultivation. CRC Critical Reviews in Food Science and Nutrition. 1987;**26**:157-223

[32] Gaitán-Hernández, R., Salmones, D., Pérez Merlo, R., & Mata, G. (2006). *Manual práctico del cultivo de setas: aislamiento, siembra y producción (1a edición). Xalapa: Instituto de Ecología* A.C. http://doi.org/970-709-042-1

[33] Oei P. Small-scale Mushroom Cultivation. Oyster, Shiitake and Wood Ear Mushrooms. Wageningen, The Netherlands: Digigrafi; 2005

[34] Abeer H, Alqarawi AA, Al-Huqail AA, Abd Allah E. Biochemical composition of *Pleurotus ostreatus* (Jacq.) P. Kumm. grown on sawdust of *Leucaena leucocephala* (Lam.) De Wit. Pakistan Journal of Botany. 2013;**45**:1197-1201

[35] Mamiro D, Mamiro P. Yield and mushroom size of *Pleurotus ostreatus* grown on rice straw basal substrate mix*ed and supplemented* with various crop residues. Journal of Animal and Plant Sciences. 2011;**10**:1211-1218

[36] Lazo-Lemun G. Determinación de la eficiencia del rastrojo de tomate (Lycopersicon sculentum Miller) y la corona del fruto de piña (*Ananas comosus* L – Merril) y sus mezclas en el cultivo de cela cepa esc 0110 de *Pleurotus* (*Pleurotus ostreatus*). Thesis Universidad de San Carlos de Guatemala, Guatemala. 2001. Available from: http://biblioteca.usac.edu.gt/tesis/01/01_1992.pdf [Accessed: March 12, 2017]

[37] Teixeira Souza RA, et al. Nutritional composition of bioproducts generated from semi-solid fermentation of pineapple peel by edible mushrooms. African Journal of Biotechnology. 2016;**15**:451-457

[38] Rashad, M. M., Abdou, H. M., & Mahmoud, A. E. (2016). Production of some bioactive materials by Pleurotus ostreatus from pineapple residues and rice straw via solid state fermentation. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 7(**5**):2730-2736.

[39] Garcia GW, Ferguson TU, Neckles FA, Archibald KAE. The nutritive value and forage productivity of *Leucaena leucocephala*. Animal Feed Science and Technology. 1996;**60**:29-41

[40] Kang B, Sipkens L, Wilson G, Nangju D. Leucaena (*Leucaena leucocephala* (Lam) de Wit) prunings as nitrogen source for maize (*Zea mays* L.). Fertility Research and Practice. 1981;**2**:279-287

[41] Sotelo A, López-García S, Basurto-Peña F. Content of nutrient and antinutrient in edible flowers of wild plants in Mexico. Plant Foods for Human Nutrition. 2007;**62**:133-138

[42] García-Mateos R, Soto-Hernández M, Vibrans H. Erythrina Americana Miller ('Colorín'; Fabaceae), a versatile resource from Mexico: A Review. Economic Botany. 2001;**55**:391-400

[43] Ragunathan R, Gurusamy R, Palaniswamy M, Swaminathan K. Cultivation of *Pleurotus* spp. On various agro-residues. Food Chemistry. 1996;**55**:139-144

[44] Aguilar-Rivera N, Castillo-Moran A, Rodriguez-Lagunez DA, Murguia-González J. In: Andres S, Baumann N, (editors). Mushrooms: Types, Properties and Nutrition. Nova Science Publisers; New York USA. 2012;77-104

[45] Flores Ramírez G. Aprovechamiento del bagazo residual de Yucca spp como sustrato para la producción de *Pleurotus* spp. Thesis Instituto Politécnico Nacional, México. 2012. Available from: http://hdl.handle.net/123456789/19825 [Accessed: March 10, 2017]

[46] Sang-Sun L, Soon-Keun K, Tae-Soo L, Min-Woong L. Cultivation of oyster mushroom using the garlic peel as an agricultural by-product. Korean Journal of Medical Mycology. 1997;**25**:268-275

[47] Lechner, Bernardo E. and Santiago Monaldi. 2011. "Utilization of Garlic and Maize Wastes Supplemented with Olive Mill Waste Water for Pleurotus Ostreatus Cultivation." *Revista mexicana de micología* **34**:17-22.

[48] Silva SO, da Costa SMG, Clemente E. Chemical composition of *Pleurotus pulmonarius* (Fr.) Quél., substrates and residue after cultivation. Brazilian Archives of Biology and Technology. 2002;45:531-535

[49] Alejo-Cristobal P, Martínez-García R, León-Avedaño H. Eficiencia biológica de *Pleurotus* spp nativo de Oaxaca (ITAO-27) sobre rastrojos de frijol, maíz y olote. Revista Mexicana de Agroecosistemas. 2015;**2**:99-106

[50] Obodai M, Cleland-Okine J, Vowotor KA. Comparative study on the growth and yield of *Pleurotus ostreatus* mushroom on different lignocellulosic by-products. Journal of Industrial Microbiology and Biotechnology. 2003;**30**:146-149

[51] Bonatti M, Karnopp P, Soares HM, Furlan SA. Estudo da composição de cogumelos das espécies *Pleurotus ostreatus* e *Pleurotus sajor-caju* cultivados em palha de bananeira. Rev. Saúde e Ambient. 2008;**4**:31-35

[52] Girmay Z, Gorems W, Birhanu G, Zewdie S. Growth and yield performance of *Pleurotus ostreatus* (Jacq. Fr.) Kumm (oyster mushroom) on different substrates. AMB Express. 2016;**6**:87

[53] Shankar Patel S, Birwal P, Singham P, Sushant Sukhdev B, Kumar Nema P. Effect of pre-treatment by onion extract on quality of dried oyster mushrom (*Pleurotus sajor-caju*). Environment and Ecology. 2016;**34**:2591-2595

[54] Ananbeh, K. and A. Almomany. 2008. "Production of Oyster Mushroom (Pleurotus Ostreatus) on Tomato Tuff Agrowaste." *Dirasat, Agricultural Sciences* **35**:133-38.

[55] Rios MM, del P, Hoyos JL, Mosquera SA. Evaluation of parameters production of the seed *Pleurotus ostreatus* spreed in different cuture media. Biotecnología en el Sector Agropecuario y Agroindustrial. 2010;**8**:86-94

[56] Obodai M, Cleland-Okine J, Vowotor KA. Comparative study on the growth and yield of *Pleurotus ostreatus* mushroom on different lignocellulosic by-products. Journal of Industrial Microbiology and Biotechnology. 2003;**30**:146-149

[57] Kurt S, Buyukalaca S. Yield performances and changes in enzyme activities of *Pleurotus* spp. (*P. ostreatus* and *P. sajor-caju*) cultivated on different agricultural wastes. Bioresource Technology. 2010;**101**:3164-3169

[58] Sentíes-Herrera HE, Gómez-Merini FC, Valdéz-Balero A, Silva-Rojas HV, Trejo-Téllez LI. The agro-industrial sugarcane system in Mexico: Current status, challenges and opportunities. Journal of Agricultural Science. 2014;**6**:26-54

[59] Muez-Orobia, M. A., & Pardo-Nuñez, J. (2001). La preparación del substrato. In J. E. Sanchez & D. J. Royse (Eds.), *La biología y el cultivo de Pleurotus spp*. México: El Colegio de la Frontera Sur. 2001;157-186.

[60] Ahmed S. Performance of Different Substrates on the Growth and Yield of Oyster Mushroom *Pleurotus sajor-caju* (Fr.) Sing. Salna, Gazipur, Bangladesh: Institute of post-graduate studies in Agriculture; 1998

[61] Carrera, M., D. Morales, and MP Sobal. 1990. "Cultivo de Pleurotus Ostreatus Sobre Bagazo de Caña Enriquecido Con Pulpa de Café O Paja de Cebada." *Micología Neotropical Aplicada* **3**:49-52.

[62] Soto-Velasco, C. L., L. Guzman-Dávalos, and C. Téllez. 1991. "Substrates for Cultivation Pleurotus in Mexico, II. Sugar Cane Bagasse and Corn Stover." *Mushroom Journal of Tropics* 11:34-37.

[63] Aguilar-Rivera, N. and J. De Jesús-Merales. 2010. "Edible Mushroom Pleurotus Ostreatus Production on Cellulosic Biomass of Sugar Cane." *Sugar Tech* **12**(2):176-78.

[64] Verma, R. N. (2001). Aspectos económicos de la producción de Pleurotus spp. In J. E. Sanchez & D. J. Royse (Eds.), *La biología y el cultivo de Pleurotus spp*. México: El Colegio de la Frontera Sur. 2001;273-290.

[65] Gaytan-Hernández, R. (2007). Transferencia de tecnología de cultivo de Pleurotus spp como alternativa de beneficio social y económico en el estado de Veracruz. In J. E. Sanchez, D. Martínez-Carrera, G. Mata, & H. Leal-Lara (Eds.), *El cultivo de setas Pleurotus spp. en México*. México: El Colegio de la Frontera Sur. 2007;101-112.

[66] Castañeda-de-Leon VT, Leal-Lara H. In: Sanchez JE, Martínez-Carrera D, Mata G, Leal-Lara H, (editors). El cultivo de setas *Pleurotus* spp. en México. El Colegio de la Frontera Sur. 2007. pp. 81-90

[67] FIRA. Panorama Agroalimentario de trigo. (2014). Available from: https://www.gob.mx/cms/uploads/attachment/file/61954/Panorama_Agroalimentario_Trigo_2015.pdf [Accessed: January 31, 2017]

[68] Robles Martinez F, Gerardo Nieto O, Pina Guzman AB, Montiel Frausto L, Colomer Mendoza FJ, Orozco Alvarez C. Obtaining alternate fuels from the biodrying of fruits and vegetables. Revista Internacional de Contaminacion Ambiental. 2013;**29**:79-88

[69] Yaoning C, et al. Nitrite reductase genes as functional markers to investigate diversity of denitrifying bacteria during agricultural waste composting. Applied Microbiology and Biotechnology. 2014;**98**(9):4233-4243

[70] Saranraj P, Stella D. Composting of sugar mill wastes: A review. World Applied Sciences Journal. 2014;**31**(12):2029-2044

[71] Saldaña María I, et al. The influence of organic fertilizers on the chemical properties of soil and the production of Alpinia purpurata. Ciencia e Investigación Agraria. 2014;**41**(2):215-224

[72] NOM-021-SEMARNAT, 2000. México. Available from: http://biblioteca.semarnat.gob.mx/janium/Documentos/Ciga/libros2009/DO2280n.pdf [Accessed: January 31, 2017]

[73] Jara-Samaniego J, et al. Composting as sustainable strategy for municipal solid waste management in the Chimborazo Region, Ecuador: Suitability of the obtained composts for seedling production. Journal of Cleaner Production. 2017;**141**:1349-1358