Sustainable Development for Farmers Transforming Agroindustrial Wastes into Profitable Green Products

Noé Aguilar-Rivera and Teresita de Jesús Debernardi-Vázquez

Abstract The world population is facing significant changes in the supply of food, feed, fuel and fiber from agroindustrial byproducts. However, poverty, climatic and environmental effects, loss of productivity of major agroindustrial activities, low-use of byproducts, land-use change, biodiversity loss and high water consumption are among some of the factors that contribute to reducing the profitability of traditional agribusinesses. The development of sustainable low-cost technologies, which are simple for rural farmers to apply for byproduct valorization is, therefore, a key option to transform traditional agribusiness in sustainable value chain. This paper proposes, to develop in farms, three productive activities, to achieve the socioeconomic and environmental sustainability with byproducts, as raw material, from the sugarcane, coffee, banana, corn and citrus fruit agroindustries in Mexico, integrating innovative techniques reported in the literature, traditional knowledge, experience of farmers and analytical methods: (a) biodrying for removal of water in byproducts, causing a decrease in volume and an increase in calorific value, (b) production of compost, vermicompost and bocashi and (c) cultivation and harvest of edible mushrooms. These activities have had a positive impact on the sustainability and profitability of farmers in Mexico by reducing the amount of mineral fertilizers used in fields, obtaining rural fuel and generating income; additionally, food is generated for humans and livestock from the production of edible mushrooms.

Keywords Agroindustrial byproducts · Sustainable technology · Farms

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W. Leal Filho et al. (eds.), *Sustainable Development Research and Practice in Mexico and Selected Latin American Countries*, World Sustainability Series,
https://doi.org/10.1007/978-3-319-70560-6_4

1 Introduction

Agroindustrial byproducts and wastes present complex widespread problems with considerable socioeconomic and environmental consequences in developed countries. However, there is great interest in the use of agroindustrial byproducts because they contain large amounts of sugars and lignocellulosic biomass that make them potentially excellent raw materials for sustainable biotechnological and conventional technological transformation processes, resulting in the production of new added-value products with specific properties (Cañete-Rodríguez et al. 2016; Kusch et al. 2015; Galanakis 2012).

Byproducts may constitute as much as 70% of crops after harvest or agroindustrial processing and considerable attention has been placed on converting them into sustainable products. Treatment of solid waste generated from agricultural and agroindustrial production activity is another serious problem in developing countries such as Mexico, where the main agroindustrial crops (Table 1) are produced under the rainfed system and low irrigation, are highly vulnerable to climatic change and other environmental and anthropic effects and with high generation of by-products due to the lack of agro-industrial technology (Figs. 1 and 2)

Therefore, technologies of recycling, reuse and sustainable use of by-products, could reduce contamination and spaces required for disposal. Therefore, it is necessary to evaluate major challenges and technologies to determine the most realistic

Table 1 Main agro industrial crops of Mexico (SIAP 2016)

Crop	Producing municipalities (#)	Harvested acreage (ha)	Production (t)	Yield (t/ha)
Corn	2343	7,099,723.8	24,694,046.25	3.48
Pastures	864	2,560,399.04	50,923,935.93	19.89
Sorghum	637	1,658,673.66	5,195,388.74	3.13
Bean	1810	1,555,131.7	969,146.28	0.62
Wheat	549	819,928.09	3,710,706.27	4.53
Sugar cane	267	758,607.94	55,396,061.34	73.02
Coffee	489	664,885.1	1,026,251.98	1.54
Forage maize	492	539,116.78	13,660,717.7	25.34
Alfalfa	821	384,375.63	32,575,005.78	84.75
Orange	457	318,379.6	4,515,520.33	14.18
Mango	392	182,680.07	1,775,506.77	9.72
Avocado	543	166,944.96	1,644,225.86	9.85
Lemon	545	160,083.58	2,326,068.34	14.53
Chile	741	148,688.77	2,782,340.75	18.71
Cotton	45	133,232.3	593,439.49	4.45
Nut	247	79,080.23	122,714.05	1.55
Banana	218	77,548.95	2,262,028.25	29.17

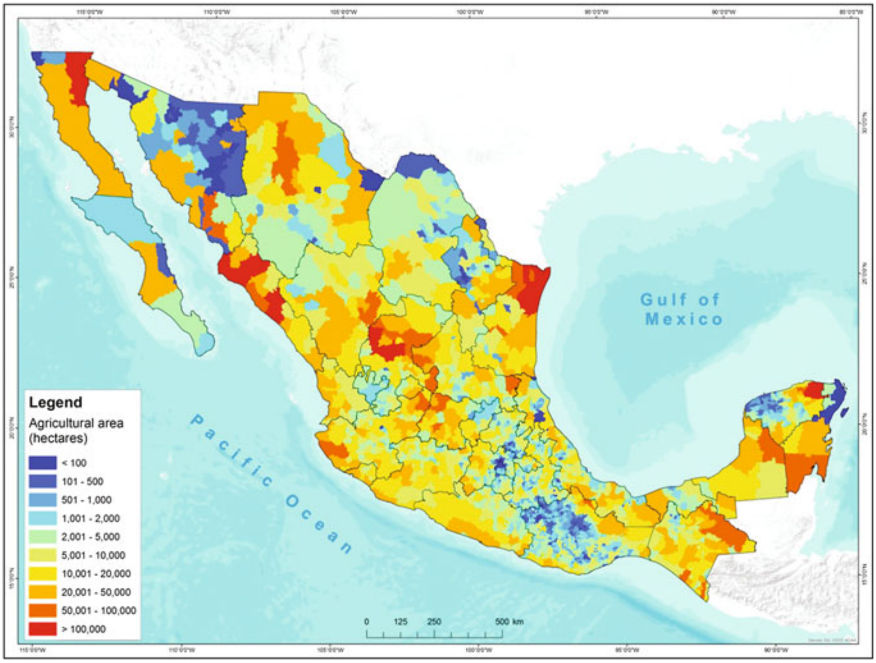


Fig. 1 Most important crops in Mexico (SIAP 2016)

options for the use of byproducts and construction of a sustainable future based on the environmental rationality. Certain agroindustrial byproducts may be used directly as animal feed or manure while byproducts from the sugar, rice, corn and soy agroindustries, among others, can in general be transformed into the 4Fs (Food–Fiber–Fuel–Feed) or raw material for sustainable process design, green engineering and biorefineries considering competitiveness according to Hanes and Bakshi (2015), as well as both, the physical amount of byproduct produced and the environmental impacts. Therefore, new technologies, traditional knowledge, experience, analytical methods from physical and chemical sciences and frameworks, to quantify the environmentally sustainable and socioeconomically feasible potential of agroindustrial residues to generate novel and greener products, bring opportunities for the design of processing value chains, as the main target of sustainability in farms. Mirabella et al. (2014); Koutinas et al. (2014); Pfau et al. (2014) and Vandermeersch et al. (2014) carried out an extensive review of the possible uses of byproducts and wastes under the bioeconomy concept in order to transform them into resources for production of new products and energy, applying industrial ecology and eco-innovative approaches.

Therefore, the aim of this research was to integrally evaluate the use of byproducts to help achieve sustainability strategies in farm and agroindustrial activities by determining their potential as lignocellulosic substrates, with the use of

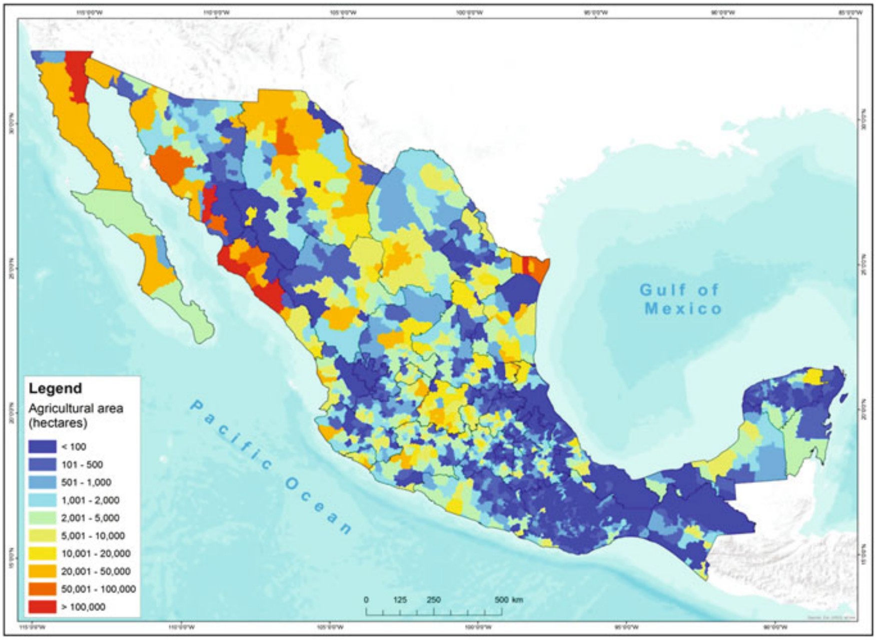


Fig. 2 Irrigated crops in Mexico (SIAP 2016)

analytical methods, low-cost processing technologies, traditional knowledge and experience of farmers, to obtain greener products: solid biofuel, compost and edible mushrooms (*Pleurotus ostreatus*).

2 Biofuel from Biodrying of Byproducts

There are several treatments for final waste disposal, but some of them require processes that entail high implementation costs. More recently, incineration has attracted global attention as an effective way of reducing the amount and toxicity of organic wastes, in addition to recovering energy from them despite their high moisture content (Ma et al. 2016).

Biodrying is a self-heating process in which the drying is carried out by the biological heat that is produced during the in situ decomposition of the organic matter, which offers an alternative for waste handling in terms of feasibility and costs (Tom et al. 2016). The objective of biodrying is to use the heat generated by the metabolic functions of the microorganisms present in the wastes, maintaining their calorific value which allows storing them as solid fuel (Sugni et al. 2005; Dominczyk and Ledakowicz 2014), where the main advantage is the reduction of mass and atmospheric emissions of CH_4, CO_2, SO_2 and NO_x (Suksankraisorn et al. 2010).

Biodrying is performed aerobically, in which the convective evaporation process is used to reduce the water content in the substrate, with minimal aerobic degradation (Velis et al. 2009).

In the particular case of residues from the citrus agroindustry, the large volume of crop residues and byproducts generated during juice extraction, particularly in the case of Valencia orange (*Citrus sinensis*), and rising waste disposal costs have led to increased interest in using these materials (Siles et al. 2016) (Figs. 3 and 4)

The main byproducts used are fresh citrus pulp, citrus silage, dry pulp, molasses, citrus peel liquor, citrus activated sludge and, to a lesser extent, waste or surplus harvest fruit (Okino Delgado and Fleuri 2016; Mamma and Christakopoulos 2014; Fava et al. 2013). Figure 5 presents the fresh composition of different citrus fruits obtained by analytical techniques.

In the figure above it can be seen that, except for the Mexican lemon, the highest proportion in weight for citrus fruits corresponds to the husk and bagasse, followed by the juice that is the product of interest. This type of byproduct contains a high moisture content, which hinders its final disposal as it tends to generate leachates and bad odors. Figures 6 and 7 show the moisture percentage in the husk and bagasse and the pulp of the evaluated citrus fruits.

In biodrying, the variables that affect the process include the initial moisture of the substrate and the airflow. The latter can be manipulated to control the

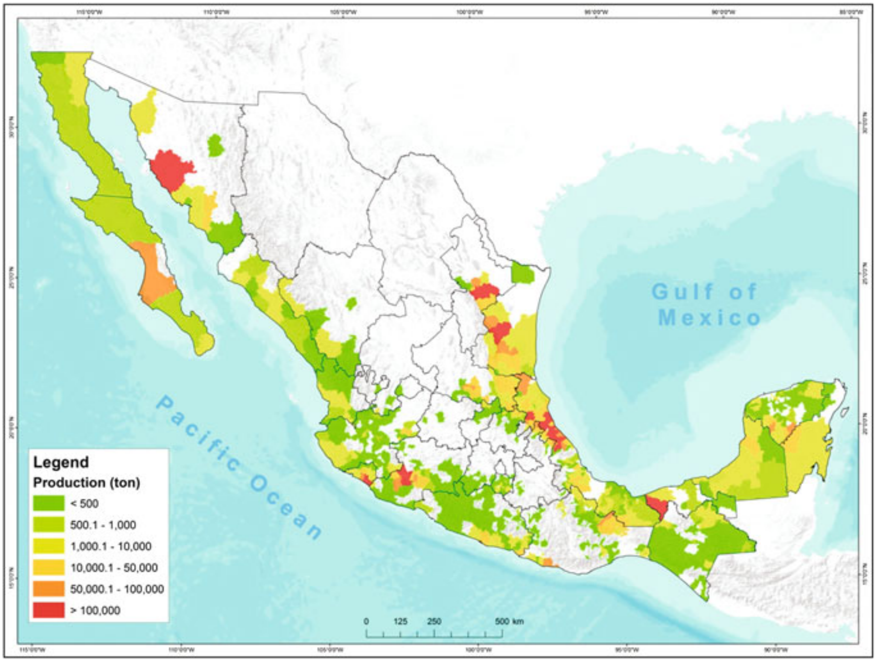


Fig. 3 Citrus in Mexico (SIAP 2016)

Fig. 4 Citrus and wastes

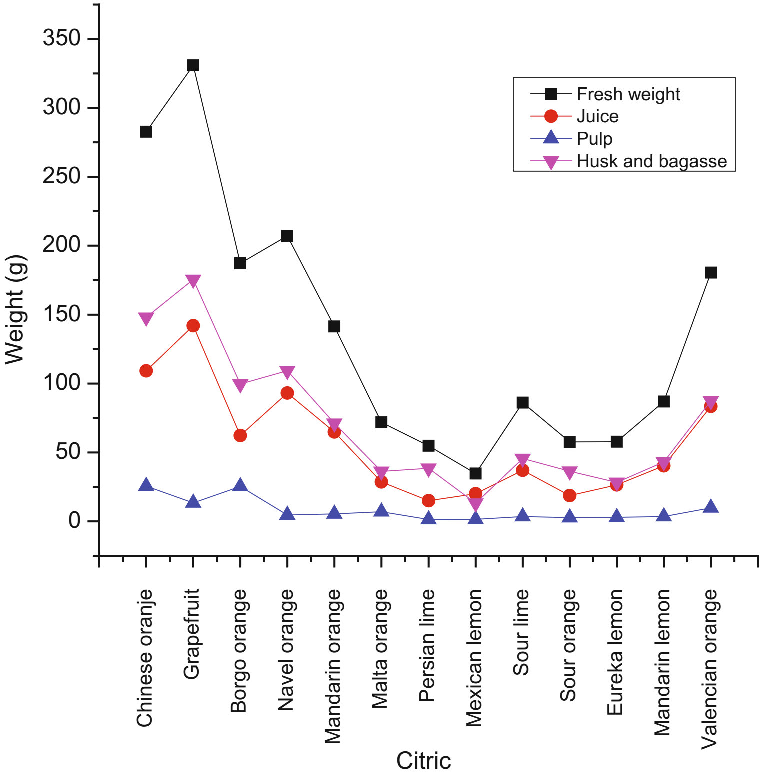


Fig. 5 Fresh composition of some citrus fruits

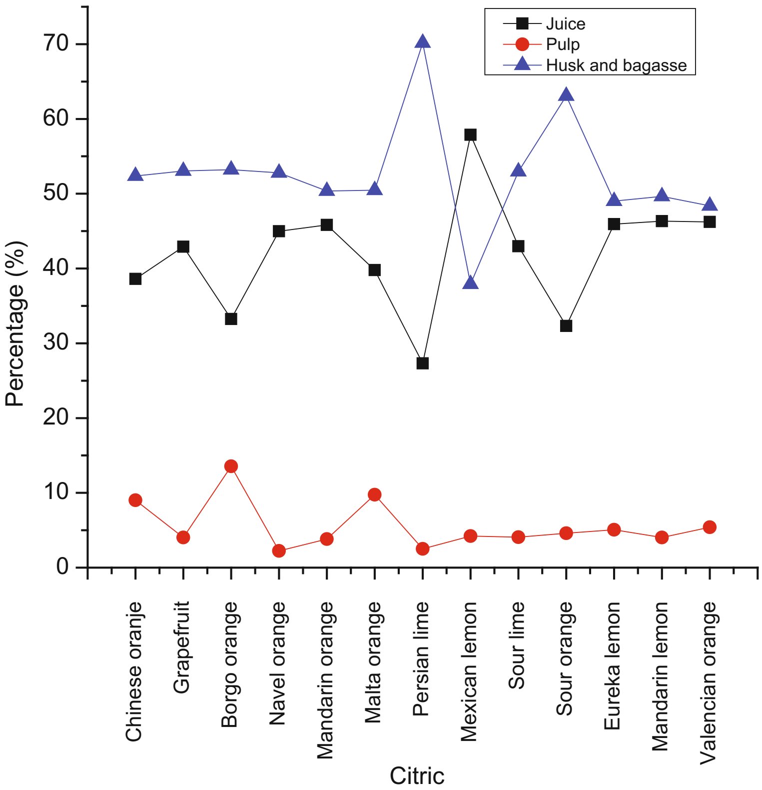


Fig. 6 Composition of citrus fruit byproducts (%)

temperature in the substrate matrix, as it affects the air dew point and biodegradation kinetics (Velis et al. 2009). In other words, the effect of air flow and turning frequency in sludge biodrying, by increasing the air flow, is to obtain higher water removal efficiency, while Cai et al. (2013) found that forced aeration controls the temperature of the pile and improves evaporation; thus, the loss of water is the key factor in sludge biodrying.

Moisture is a critical parameter in biodrying, since it influences the complex biochemical reactions associated with the growth of microorganisms and the biodegradation of organic matter that occurs in the process (Winkler et al. 2013). Thus, the excess prevents the transfer of oxygen and the microbial activity is reduced, which impedes the development of the process; in the contrary case, if the moisture is very low, the microbial activity becomes too slow and thus affects the drying process. According to Yang et al. (2014), the optimum moisture level for the biodrying process to be performed efficiently is in the range of 50–70%.

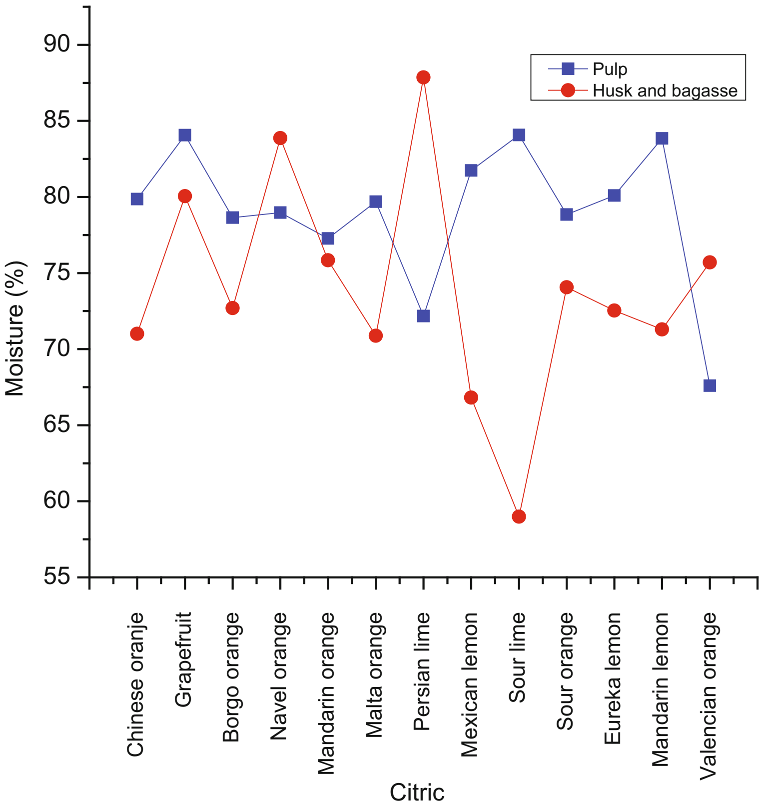


Fig. 7 Moisture in the husk and bagasse and pulp of different citrus fruits (%)

He et al. (2013) found that temperature is one of the key variables in biodrying, as a temperature increase in the matrix increases air temperature, which improves its ability to remove water from the substrate.

In the sustainable process at the farm level, a static biodrying pile with a rectangular pyramidal structure was used; in it, 9 points were established for the permanent monitoring of the inside temperature. As a mechanism to maintain the aeration process in the substrate matrix, a forced aeration system was used, providing a volume of 25 L/min. The aeration process was performed every 2 h with a volume of 125 L/min from 8:00 a.m. to 4:00 p.m. during the time of the experiment (Fig. 8a, b).

For temperature monitoring, an RTD data acquisition system connected to a Snap Pac System Opto 22, which operated 24 h a day, was used. To prevent the substrate from getting wet as a consequence of weather changes, the experiment was carried out in a greenhouse-type drying tunnel. The materials used for preparing the pile are listed in Table 2.

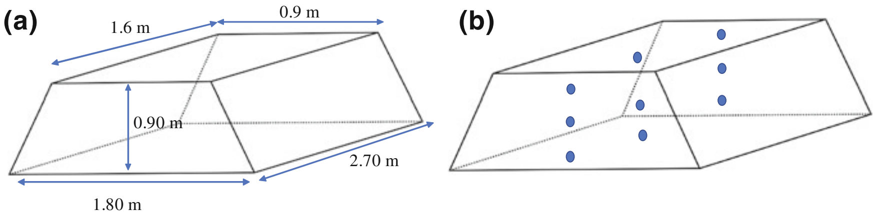


Fig. 8 Geometry of the biodrying pile and sampling points

Table 2 Materials for biodrying

Waste	Amount (kg)	Percentage (%)
Orange peel	200	56.0
Mulch (pruning waste)	88.9	24.9
Grass	68.3	19.1
Total	357.2	100

Grass and mulch were used as structuring materials in order to favor the formation of a porous matrix inside the pile that allowed air flow.

In semistatic biodrying piles, four phases can be observed in the evolution of the temperature: initiation phase, thermophilic phase, second heating phase and decay phase (Cai et al. 2013). This is due to the fact that when turning the materials that make up the pile, its interior is homogenized and the gradients in the concentration of oxygen, available water and nutrients for the microbial activity in it, which are affected by leaving the pile static, are changed; although there are changes in the behavior of the temperature, it remains more homogeneous throughout the process. The behavior of the temperature in the center of the biodrying pile is shown in Figs. 9, 10 and 11; the data used for making the graph correspond to the temperatures recorded at 10:00 am. A uniform distribution is observed in the central layer of the pile, with temperatures ranging from 23 °C, which was the ambient temperature on the day the pile was formed, to 67 °C, which was the maximum value reached in this layer.

According to Colomer-Mendoza et al. (2013) and Cai et al. (2013), there is a reduction in the volume of the pile as a result of the loss of water in the substrate matrix. This phenomenon is due to the evaporation of water by a convective mechanism, i.e., the air entering the matrix in a forced manner carries a certain amount of water that favors the hydration or dehydration of the matrix; moreover, the higher the temperature of the incoming air, the greater its capacity to remove water from the substrate However, if this phenomenon occurs the drying of the materials occurs in a convective way and not due to the effect of the heating caused by the metabolism of the thermophilic microorganisms which are a mixture of yeasts, bacteria and fungi.

While in the middle section of the pile the higher temperature lasted longer, on the sides it decreased as the process progressed. This phenomenon can be attributed

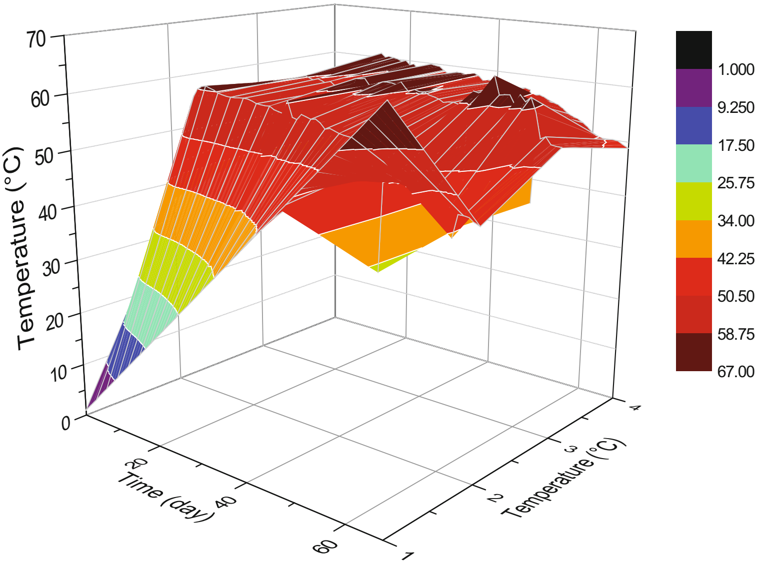


Fig. 9 Temperature in the central section of the biodrying pile

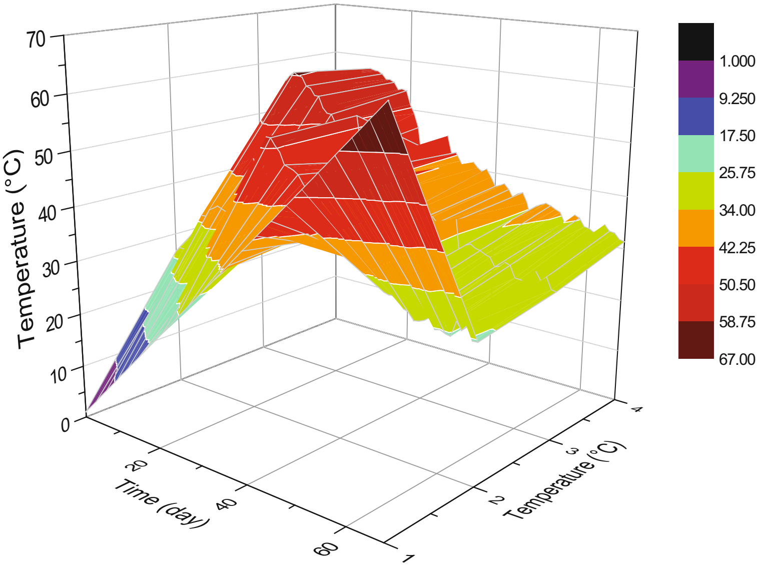


Fig. 10 Temperature in the left section of the biodrying pile

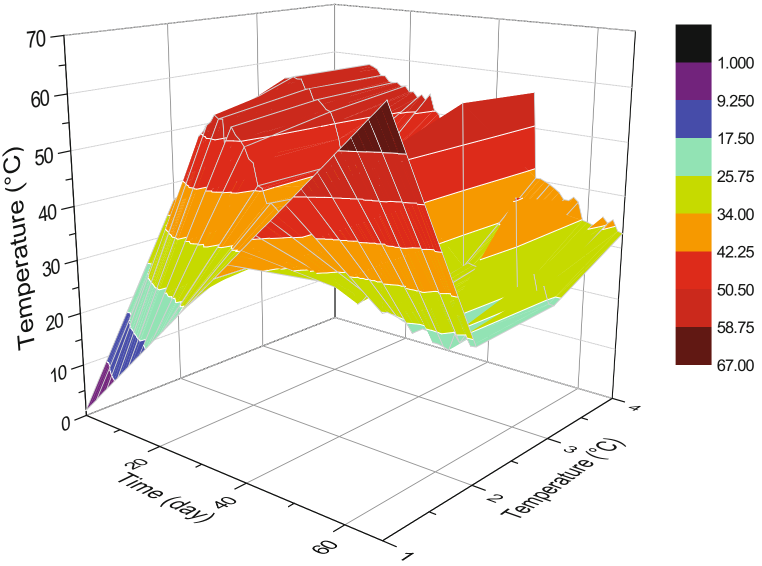


Fig. 11 Temperature in the right section of the biodrying pile

to the fact that, because the pile was not turned, the higher moisture content was concentrated in the center; the material that was located on the surface caused an insulating effect that helped to maintain moisture and allow the process to last up to 67 days, while the normal process with periodic turnings lasts for 20–30 days (Fabián et al. 2012).

It was observed that the maximum temperature was between 60 and 67 °C, decreasing until reaching the ambient temperature, once the microorganisms present no longer have available water to continue the substrate degradation process (Fig. 12).

According to the evolution of the substrate moisture and the temperature behavior in the pile, it can be observed that the moisture is directly linked to the activity of the microorganisms, since as the temperature decreases it tends to stabilize. It is desirable that the biodrying process be carried out in short periods of time in order that the substrate is degraded as little as possible and maintains its calorific value to be incinerated or stored as biofuel for energy cogeneration. Although this stabilized waste can be deposited directly in waste confinement areas for final disposal without the problem of leachate generation (Fabián et al. 2012), another advantage of the process is that there is a reduction in its volume and mass of up to 74%, which facilitates its transport and storage and reduces final treatment costs. Table 3 presents the results of the laboratory analysis according to Mexican standard NOM-021-SEMARNAT (2000) for chemical composition.

The final product presented a humidity of 12.31%, pH 4.92, organic matter 94.24%, which is important for its use as a rural fuel because it guarantees that the

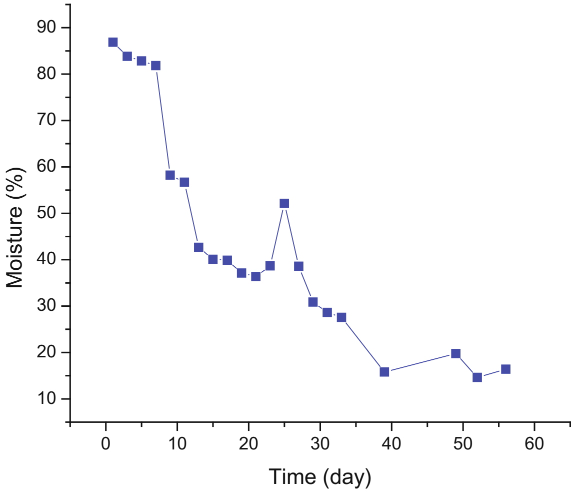


Fig. 12 Decrease in substrate moisture (%) (moisture balance method)

Table 3 Chemical composition of biodried biofuel from citrus

Variable	Unit	Value
Humidity	(%)	12.31
pH		4.92
Soil electrical conductivity	dsm^{-1}	1.45
Ash	(%)	5.76
Organic matter	(%)	94.24
Total carbon C	(%)	54.64
Total nitrogen N	(%)	1.13
C/N		48.38
Ca	(%)	1.544
Mg	(%)	0.186
Na	(%)	0.059
K_2O	(%)	0.934
P_2O_5	(%)	0.273
Fe	(%)	0.0448
Cu	(%)	0.0007
Zn	(%)	0.0034
Mn	(%)	0.0193

ash content at the end of the incineration will be low, with respect to the nitrogen content of 1.13% and carbon of 54.664% with a C/N ratio of 48.38 which is desirable for biodried fuels from biomass which are destined for incineration, favoring a low NOx formation Dominczyk and Ledakowicz (2014).

3 Edible Mushroom Production from Byproducts

Processing of agroindustrial plantations generates wastes in the field as leaves, stalks, straws or bagasses which necessitate the search, as substrates, for new alternatives for effective production as the cultivation of edible mushroom. In fact, cultivation of *Pleurotus* mushrooms is considered to be a simple, low cost and environmentally friendly technology for the utilization of rural and agroindustrial residues in developing countries (Mohamed et al. 2016; Kazemi Jeznabadi et al. 2016; Yang et al. 2016; Corrêa et al. 2016).

Several substrates were evaluated for edible mushroom (*Pleurotus ostreatus*) cultivation, namely byproducts derived from sugarcane, coffee, banana and corn plantations or processing plants (some of the main agroindustries in Mexico) (Fig. 13).

Fig. 13 Lignocelullosic by products from agroindustries

Pleurotus ostreatus, also known as oyster mushroom or white rot fungi, is one of the most common mushroom production systems worldwide. Mushroom cultivation provides direct bioconversion of solid wastes into edible biomass (Philippoussis 2009). The *Pleurotus* species requires a short growth time, compared to other mushrooms. Its fruiting body is not often attacked by pests and diseases and it can be grown in a simple and cheap way, with high yield, wider substrate utilization, sporelessness, wide temperature and chemical tolerance, as well as environmental bioremediation (Bellettini et al. 2016). For this process, substrate preparation is the most critical step (Vieira and de Andrade 2016).

The byproducts, intended for use as substrates after being collected, were completely dried under the sun, chopped, washed, soaked in cold water for at least 24 h to obtain a water content of 65–75%, sterilized with conventional heat treatment by immersion in hot water at 85 °C and deposited in a plastic container before being inoculated by hand with spawn. The average temperature was 24–30 °C and relative humidity was 50–65%. In order to determine suitable substrates and suitable ratios for the cultivation of oyster mushroom, the colonization and fructification times, yield, biological efficiency and productivity according to the literature were studied (Gaitán-Hernández and Salmones 2008; Mata et al. 2013; Héctor et al. 2013; Sözbir et al. 2015; Sardar et al. 2016).

Biological efficiency (BE) is determined as the ratio between the fresh edible mushroom or *Pleurotus* fruiting body weight produced and the dry weight of the substrate, while the rate of production (P) is calculated by the biological efficiency by the total number of days of evaluation, being considered from the first day of incubation of the spawn in the substrate until the last day of harvest. The yield (R) is determined as the weight of the produced edible mushroom from the wet weight of the substrate used, expressed as a percentage (Table 4).

$$\mathrm{BE}\ (\%) = \frac{\text{Fresh edible mushroom (g)}}{\text{dry weight of the substrate}} \times 100$$

$$\text{Productivity} = \frac{\mathrm{BE}\ (\%)}{\text{Days of evaluation}} \times 100$$

$$\text{Yield}\ (\%) = \frac{\text{Fresh edible mushroom (g)}}{\text{Wet weight of the substrate}} \times 100$$

The first harvest occurred after 21 days of incubation for corn leaves, and maize tops and the last after 49 days for banana leaves. Mushroom weight, cap diameter and stipe length development in oyster mushroom were significantly affected by substrate types. Productivity varied from 0.41 for leaves and coffee stem plant to 3.64% for maize leaves. Similarly, the highest yield value, 20%, was obtained with banana leaves and the lowest, 10%, with bagasse from mills. The water used in the washing and pasteurizing stages can be used in crop irrigation.

Several substrates had a comparatively higher mycelial growth rate, a shorter total colonization period, a larger cap diameter (4.5–15 cm) and a shorter stipe length (3.5–7 cm), mostly in leaf substrates. The rest had a smaller mushroom cap

Table 4 Productivity and physical characteristics of edible mushroom

Substrate	Days of treatment (incubation to harvest)	Productivity (%)	Yield (%)	Average cap diameter (cm)	Average stipe length (cm)
Bagasse from mills	22	1.36	5.5	6	3.8
Bagasse trapiche/bagasse mills (50/50)	22	1.82	5.88	5.8	3.7
Bagasse pith	23	1.74	8.89	5.3	4.9
Banana leaves	49	2.55	20	15	5.7
Banana stem	40	0.7	5.92	9	5.3
Banana trash	25	2.6	12.04	9.5	7
Coffee husk	22	1.14	6.98	8	4.3
Corn cob	28	2.2	15.42	10.9	4.5
Corn stalk	40	3.13	13.89	9	4
Corn leaves	21	2.78	8.75	6.5	4
Leaves and coffee stem plant	47	0.41	10.14	4.5	4.5
Maize flower	27	1.85	8.77	5	4.2
Maize tops	21	2.78	7	6	3.7
Maize leaves	22	3.64	10	4.5	3.7
Sugar industry mixture	23	2.52	8.53	6	3.5
Sugarcane flowers	22	2.5	9.91	7	3.8
Sugarcane tops	22	2.5	10.09	6.3	5
Sugarcane trash	22	2.27	7.69	6.3	3.7

diameter and a relatively long stipe length, which are undesirable marketing characteristics but suitable for self-consumption or processing as protein flour, or dried mushrooms, etc.

Besides, by making various substrate mixtures, BE varied significantly from 19% for leaves and coffee stem plant to 125% for corn stalks and banana leaves (Fig. 14).

At least 75% of the evaluated substrates (BE greater than 50%) are viable for the production of the mushroom *Pleurotus* on farms, especially in view of its low contamination in trials and its abundance, availability and diversity throughout the agricultural year as byproducts. Therefore, the analyzed byproducts are considered competitive substrates for the sustainable production of edible mushroom (Fig. 15).

Mushrooms obtained from substrates can be dried using direct solar radiation to avoid rapid deterioration before marketing. This processing technology also allows producers to increase the value added to mushrooms (as a high protein product),

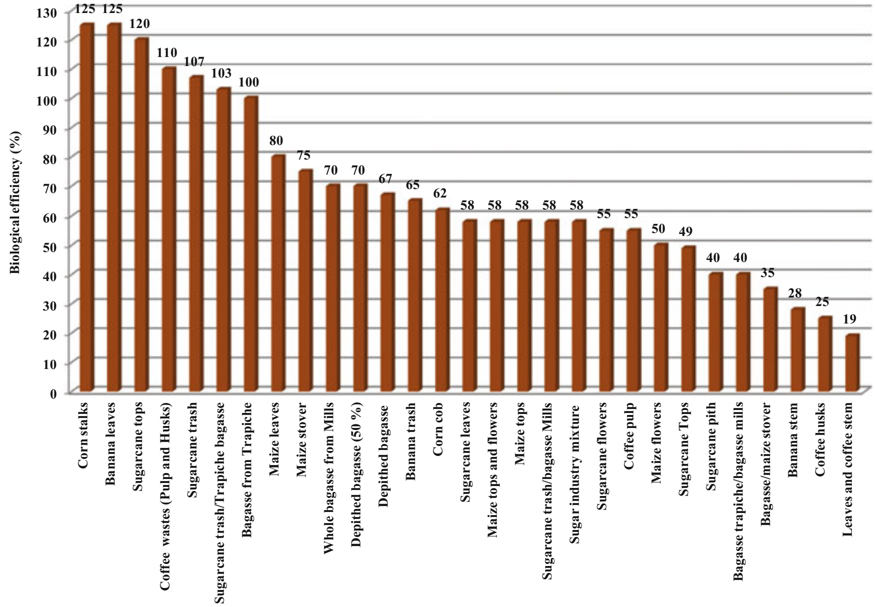
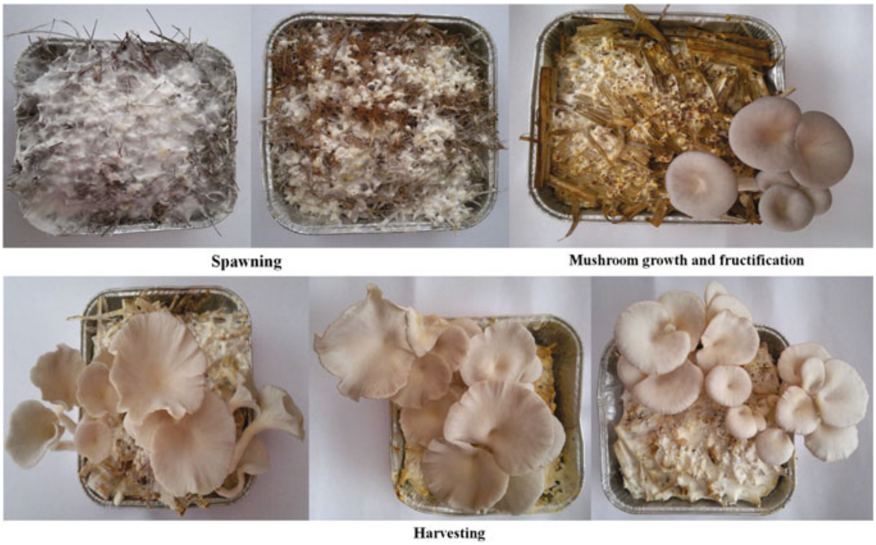


Fig. 14 Biological efficiency of treatments


Spawning

Mushroom growth and fructification

Harvesting

Fig. 15 Stages of edible mushroom production standardize quality, highlight certain food properties, and develop marketing strategies at local or national level. The spent substrates can be used as survival livestock feed or mixed with a daily ration as a source of fiber or composting. The containers can be recirculated in the next production cycle.

4 Production of Compost, Vermicompost and Bokashi

The production of manures, as an organic matter source from plantation or agroindustry byproducts, can be an alternative source of income and an option to recover soils with depleted nutrients and physical properties due to intensive use for growing plantation crops (Saldaña et al. 2014).

Composting, vermicomposting and bokashi all involve the biochemical process of aerobic decomposition of organic solid waste. They represent a low cost and environmentally-friendly waste management option involving several solid and liquid byproducts, manure from various farms and livestock, fibers, microorganisms and yeasts or earthworms that transform on-farm organic waste materials into a stable humic material, as a soil conditioner generating a useful product for farmers (Misra et al. 2016). In developing countries, conventional composting can be divided into three differentiated stages based on the temperature of the material in the process, mostly filter mud from sugar industry or sewage treatment sludge: initial mesophyll stage with a duration of 2–3 days, where the temperature follows an ascending behavior that starts with the ambient temperature and rises up to 40 °C; thermophilic stage, which has a variable duration, where the temperature increases up to 75 °C and the final mesophyll or maturation stage in which the temperature falls from 40 °C to ambient temperature. At this stage the biological stability of the material is reached (Morales et al. 2016; Van Fan et al. 2016 and Prado et al. 2013).

Sahu and Brahmaprakash (2016) discussed trends in the formulation of new organic fertilizers for agriculture. In addition, Ramos Agüero and Alfonso (2014) summarize some features related to the employment of organic manures, placing special emphasis on the development and production of fermented bokashi-type manures and their use in agriculture; moreover, composting methods, scales, and constraints have been recently reviewed by Misra et al. (2016); Qdais and Al-Widyan (2016); Pandey et al. (2016) and Lim et al. (2016).

The production of organic fertilizers from byproducts of the sugarcane, coffee, citrus and edible mushroom agroindustries can provide an alternative source of income and sustainable fertilizers for crops. Organic manures in the form of compost, vermicompost (with earthworm) and bokashi were produced according to Saranraj and Stella (2014) and Saldaña et al. (2014), and evaluated for their nutritional value according to Mexican standard NOM-021-SEMARNAT (2000) for compost analysis.

Organic manures obtained from byproducts of the local agroindustries were analyzed for their nutritional content in ten trials. The most important difference among products (Table) is the low N in filter mud (T1) and waste from the cultivation of oyster mushrooms and filter mud, bagasse and coffee (T5 and T9 respectively), which resulted in these having the lowest C/N ratios. The most attractive products for soil application are T2, T3, T6 and T7, which are high in calcium, contain a considerable amount of potassium (especially T6 and T7) and have a balanced pH. The low pH of T2, T9 and T10 is reflected in their low cation and phosphorous contents. In general, the addition of vermicompost by itself or in combination with other organic products (except the waste from the oyster mushrooms) increased the nutritional value of filter mud (Table 5 and Fig. 16).

T1 filter mud; T2 filter mud compost; T3 filter mud vermicompost; T4 filter mud vermicompost and sugarcane trash; T5 filter mud vermicompost and waste from cultivation of oyster mushrooms; T6 filter mud vermicompost and livestock manure; T7 bokashi filter mud, bagasse, $Ca(OH)_2$, yeast and molasses; T8, compost orange waste, filter mud and bagasse; T9 filter mud, bagasse and husk and coffee spent ground; T10 coffee pulp vermicompost.

Although there are differences due to the type of soil, management practices, chemical composition of byproducts and production techniques, the organic fertilizers obtained from agroindustrial byproducts can generate additional income in the crop areas; moreover, the manure encourages soil structure, fertility and nutrient availability to plants, and reduces the pH, promoting good crop development and productivity in farms in the short and medium term depending on the type of crop (Diacono and Montemurro 2015).

According to the productive options evaluated, Alwi et al. (2014) concluded that the 'engineers of the future' will have the responsibility of addressing the entire spectrum of sustainability constraints and push factors, including the economic, environmental, social and multi-generational dimensions generating *bioproducts* within the 4Fs and multidisciplinary approaches (Fig. 17)

5 Conclusions

Byproducts are produced in sugarcane, banana, corn, coffee and citrus plantations, among others, and in several agroindustries in large amounts and without any specific treatment and use. Therefore, to develop alternatives for the conversion of these wastes into value-added products through sustainable technologies in farms is a priority objective in developing countries such as Mexico, where the sustainability and the environmental, social and economic rationality is a slow process. In this work three high-value products were obtained with traditional knowledge of farmers, sustainable technologies and analytical methods: solid biofuel from citrus residues; organic fertilizers with various chemical properties for agriculture, combining various agroindustrial and livestock products; and edible mushroom from individual byproducts and mixtures thereof. These bioproducts can be obtained directly by farmers and contribute to their energy, food and economic sustainability and help them recover soils eroded by monocultures. Moreover, specialized

Table 5 Average nutrient content of organic manures from agroindustrial byproducts

Variable	Unit	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
pH		7.52	5.49	7.32	7.79	7.27	7.63	8.28	9.22	5.54	6.82
Soil electrical conductivity	dsm^{-1}	0.958	2.374	1.079	1.105	1.076	1.628	1.806	4.450	1.324	1.3
Ash	(%)	47.670	45.850	56.96	55.03	50.01	61.98	62.12	33.910	62.10	32.43
Organic matter	(%)	52.330	54.150	43.04	44.97	49.99	38.02	37.88	66.090	37.90	67.57
Total carbon C	(%)	30.354	31.409	24.965	26.085	28.996	22.053	21.976	38.335	21.984	39.194
Total nitrogen N	(%)	0.678	1.680	1.99	1.45	0.51	1.68	1.53	1.49	0.72	1.52
C/N		44.77	18.69	12.55	17.98	56.85	13.12	14.36	25.73	30.53	25.79
Ca	(%)	5.030	2.756	5.266	5.388	4.849	4.599	18.279	4.319	1.070	3.975
Mg	(%)	0.773	0.290	0.635	0.662	0.610	0.603	0.726	0.803	0.360	0.522
Na	(%)	0.0314	0.0300	0.029	0.040	0.029	0.043	0.042	0.083	0.056	0.068
K_2O	(%)	0.211	0.150	0.184	0.179	0.156	0.342	0.322	2.244	0.270	0.651
P_2O_5	(%)	3.947	2.796	3.384	3.956	3.711	3.431	2.839	2.721	0.387	3.332
Fe	(%)	0.5465	0.8961	1.088	0.898	0.7310	0.6990	0.5980	0.0170	0.5074	1.22
Cu	(%)	0.0078	0.0055	0.0156	0.0204	0.0051	0.0026	0.0047	0.0033	0.0025	0.0064
Zn	(%)	0.0216	0.0238	0.0227	0.0224	0.0324	0.0121	0.0204	0.0115	0.0087	0.0227
Mn	(%)	0.1659	0.1415	0.2227	0.2502	0.1950	0.1830	0.2205	0.0501	0.1070	0.1404

Fig. 16 Organic manure from Mexican byproducts

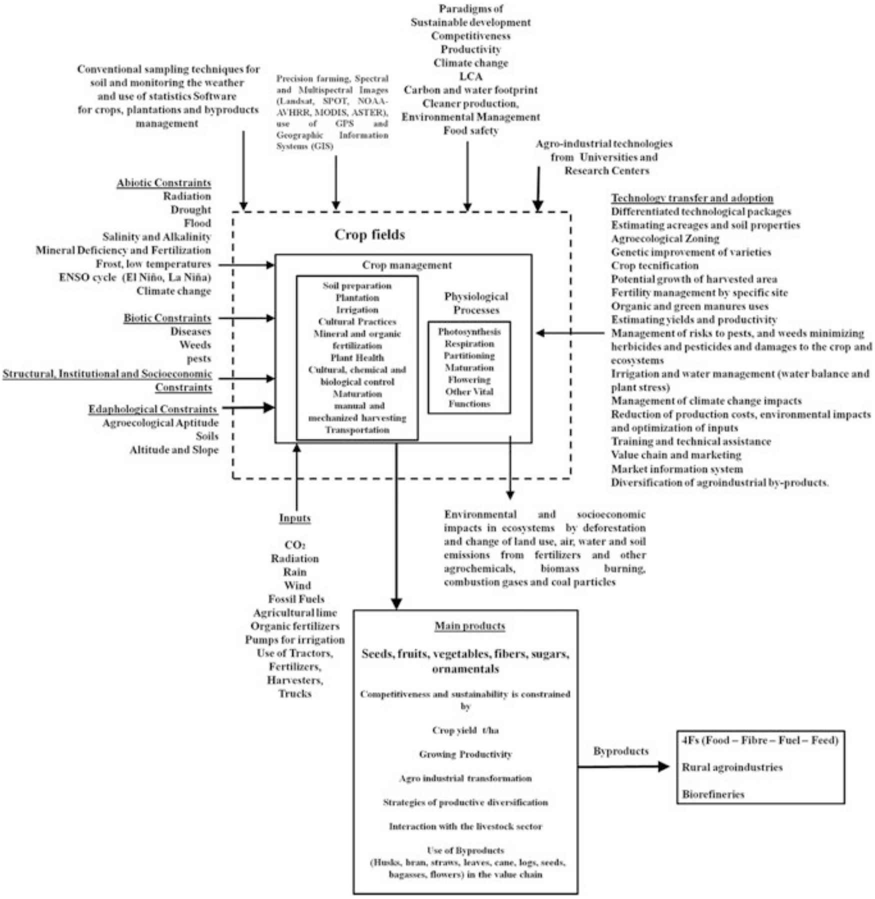


Fig. 17 Integration agroindustrial of byproducts

machinery is not required for processing and this process will potentially help to reduce the emission of greenhouse gases into the atmosphere. However, future works should be addressed to the implementation of sustainable development in agroindustries, which is a continuous process of cultural awareness and paradigm change by stakeholders (farmers, agricultural extensionists, environmentalists, policy makers, industry owners), to achieve success.

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