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Short Review

# Edible mushroom production in Ecuador: opportunities for biotechnological use of agricultural by-products

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## ABSTRACT
Recent studies estimate that there are between 1.5 and 5.1 million fungi species on Earth, and 150.000 of them have been taxonomically classified. Approximately 2.000 are suitable for food and medicinal applications, but only 35 are cultivated commercially. In Ecuador, 100.000 species are available, although only 5.000 have been taxonomically characterized. Mycoculture is the production of fungi under controlled conditions. Edible mushrooms are saprophytes, and they grow on decomposing organic substrates, mainly on lignocellulosic agricultural by-products such as sawdust, straw, bran and bagasse. Mushroom cultivation turns waste into resource, reducing pollution. Ecuador is an agriculture-based economy, and many lignocellulosic wastes are produced from permanent crops such as cocoa, African palm, sugar cane and coconut. Ecuador's inhabitants are looking for healthy and environmentally friendly products, leading to an increase in demand for locally produced mushrooms, which show high nutritional values and medicinal properties. At the global level, current studies show that edible mushroom production moves around 42 billion dollars annually, projected to 62 billion by 2023. China is the leading producer, with more than 7 million tons per year reported in 2016, followed by the United States, Italy, France and Spain. The increasing rate of edible mushroom global production stands at about 11%.

**Keywords:** fungi; waste; transformation; biotechnology; mycoprotein

## INTRODUCTION

The Earth is home to millions of fungi species (1.5 to 5.1), most still unknown. Considering these estimations, just 2.9% to 10% have undergone taxonomic classification (150.000) [1]. Of known species, 1.3% (2.000) are used daily by people worldwide for food and medicinal purposes, but just 1.7% (35) are intentionally cultivated for commercial reasons [2]. Researchers estimate that around 100.000 species were found in Ecuador, even though only 5.000 have been taxonomically characterized [3]. In tropical America, edible mushroom cultivation started in Mexico in 1933, followed in the forties by Argentina, in the fifties by Colombia, Brazil and Chile, in the sixties by Guatemala, Peru, Ecuador, Venezuela and Costa Rica and the eighties by Bolivia [4]. Cultivated edible fungi are saprophytes; they grow on decomposing organic substrates, mainly lignocellulosic agricultural by-products such as sawdust, straw, bran, and bagasse. Mushroom cultivation turns waste into resource, reducing pollution caused by them. At the global level, approximately 998 million agricultural waste is produced each year due to production intensification. That increase causes improper waste management and pollution, affecting people and the environment [5]. The production of edible mushrooms under controlled conditions is known as my-coculture, an affordable alternative to harvest from the natural environment. High volumes of fresh mushrooms are achieved through accessible technologies, allowing easier consumption in the diet, especially for those living in rural areas [6]. World production of edible mushrooms has increased from 1 to 34 million tons per year from 1978 - 2013. Current studies show that this production moves around 42 billion dollars annually, projected to reach 62 billion dollars by 2023 [7]. China stands out as the leading producer of edible mushrooms, with more than 7 million tons per year reported in 2016, followed by the United States, Italy, France and Spain[8]. On the other hand, the increasing rate of global production of edible mushrooms stands at about 11% [7].

## NUTRITIONAL VALUE OF EDIBLE MUSHROOM

Mushrooms are consumed worldwide for their nutritional value. Over 200 species are used as food, although 35 are cultivated commercially. The most cultivated mushrooms, which produce edible carpophores, belong to the Phylum Basidiomycota. The most cultivated genera in the world are *Agaricus*, *Flammulina*, *Lentinula* and *Pleurotus* [2]. Mushrooms are rich in water (80-95%), low in calories (2-3% lipid dry weight) and high in proteins (20-25% dry weight) (Table 1). They are a source of minerals such as potassium, phosphorus, magnesium, calcium, copper and zinc, as well as carbohydrates such as chitin, glycogen and hemicelluloses [2]. Edible mushroom production is environmentally, technologically, and socially sustainable since solid-state fermentation is used on agricultural wastes [8]. In addition to their high nutritional value, edible mushrooms have also medicinal properties. Bioactive compounds are found in fruiting bodies and mycelium of some species [9]. Recent studies in India showed the presence of gallic acid, hydroxybenzoic acid, quercetin and epicatechin in some species; those compounds have shown beneficial biological activities for disease prevention [10]. Edible mushrooms have also been investigated for the presence of bioactive compounds such as peptides, polyphenolic compounds, polysaccharides, oligosaccharides, dietary fibers, amino acids and micronutrients, which seems to be able to explain their biological effects [11], such as anti-inflammatory properties [12], depressive disorder [13], anti-obesity treatment [14] and diabetes mellitus [15]. Due to those effects, they have potential as nutraceuticals [16,17]. Considering the beneficial impacts on human health, edible mushrooms are also considered functional foods [18]. As reported in some research [19-21], promising *in vitro* and *in vivo* studies revealed anti-tumoral, neuroprotective, hepatoprotective, cardioprotective, immune-potentiating and hypocholesterolemic activities. A specific focus about the pivotal role of polysaccharides on gut microbiota regulation have been mentioned in two investigations [22,23], addressing the prebiotic activity of mushrooms on that specific microbiota, which enhance health benefits for the host. Also, studies on β-glucans suggested a potential clinical use of edible mushrooms in recurrent infections, cardiovascular and metabolic diseases [24,25]. Edible mushrooms have been proposed also as a source of nature-based nutraceutical compounds, which seem to be able to mitigate neurodegenerative diseases by boosting the immune-modulating response. These studies open a new trend research to ameliorate the life of patients with dementia and Alzheimer's disease and to develop new food supplements or diet strategies for brain and nervous system health [26,27]. However, consumption safety must always be guaranteed, and they must be microbiologically safe and free of toxic compounds. Production techniques must allow the conservation of mushroom nutritional and health benefit value [28,29].

| | A.b | | | A.bl | A.su | | A.sy | F.v | | L.e | | | P.e | | P.d | | P.o | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | F | F | S | Ss | S | S | Ss | Ss | S | Ss | S | S | S | S | S | S | F | S |
| **Moisture** | 91.27 ±0.45 | nd | nd | nd | 88.03 | 86.54 | 79.78 ±1.31 | 6.31 | nd | 79.78 ±1.31 | nd | nd | 89.00 ±1.39 | 91,00 | 90.07 ±0.28 | 79.52 | 89.17 ±2.12 | 45.51 | 88.50 |
| **Ash** | 0.85 ±0.17 | 9.70 | nd | 7.47 ±0.04 | 3.97 | 6.91 | 1.36 ±0.05 | 7.38 | 7,40 | 1.36 ±0.05 | 7.64 ±0.04 | 4.29 ±0.10 | 0.68 ±0.06 | 4,89 | 6.34 ±0.01 | 5.90 | 0.62 ±0.08 | 4.03 | 6.1 |
| **Proteins** | 1.23 ±0.02 | 14.10 | 29.14 | 31.29 ±1.85 | 18.65 | 29.16 | 0.89 ±0.09 | 41.16 | 27,50 | 0.89 ±0.09 | 14.45 ±0.14 | 12.76 ±0.24 | 1,21 ±0,02 | 11,95 | 20.50 ±0.00 | 35.50 | 0.76 ±0.06 | 4.35 | 32.00 |
| **Fat** | 0.19 ±0.03 | 2.20 | 1.56 | 1.82 ±0.03 | nd | 1.59 | 0.35 ±0.02 | 6.60 | 7,00 | 0.35 ±0.02 | 2.08 ±0.16 | 1.01 ±0.10 | 0,16 ±0,03 | 7,50 | 1.12 ±0.03 | 1.72 | 0.15 ±0.02 | 2.41 | 3.10 |
| **Carbohydrates** | 6.46 ±0.57 | 74.00 | 51.05 | 59.42 ±1.86 | 75.60 | 62.34 | 17.62 ±1.29 | 36.21 | 58,00 | 17.62 ±1.29 | 75.83 ±2.66 | 81.94 ±0.40 | 8,95 ±1,04 | 39,85 | 32.69 ±0.47 | 44.75 | 9.30 ±2.08 | nd | 50.90 |
| **Energy (kcal $100^{-1}$ g)** | 30.86 ±1.98 | 32.50 | nd | 379.24 ±0.29 | nd | 35.6 | 72.79 ±4.98 | nd | nd | 72.79 ±4.98 | nd | 387.89 ± 0.26 | 39,84 ±3,74 | nd | nd | nd | 39.27 ± 7.7 | nd | nd |
| **References** | 30 | 2 | 31 | 31 | 33 | 34 | 30 | 35 | 36 | 30 | 37 | 32 | 30 | 38 | 39 | 38 | 30 | 40 | 38 |

Mushrooms species: A.b (*Agaricus bisporus*), A.bl (*Agaricus blazei*), A.su (*Agaricus subrufescens*), A.sy (*Agaricus sylvaticus*), F.v (*Flammulina velutipes*), L.e (*Lentinula edodes*), P.e (*Pleurotus eryngii*), P.d (*Pleurotus djamor*), P.o (*Pleurotus ostreatus*). S: dry g $100^{-1}$ | Ss: dry % | F: fresh % nd: not available

**Table 1. Nutritional value of some edible mushrooms cultivated worldwide.**

## MUSHROOMS CULTIVATED IN ECUADOR

Native people from the coast and the Andean and Amazonian regions of Ecuador are used to ingesting mushrooms that grow in the wild. They have developed a traditional knowledge of ethnomycology, including myths as a cultural result of fungi consumption. Gamboa-Trujillo carried out studies on mushroom consumption in Ecuadorian ethnic groups distributed all around the country. Among them, eleven groups consume edible fungi of about 37 species belonging to Basidio- and Ascomycota; all have vernacular names. The most common genera were *Agaricus, Auricularia, Coprinus, Favolus, Gymnopus, Lentinus, Phillipsia, Pleurotus, Poliporus, Trametes, Volvariella* [41, 42]. Despite the vast mushroom consumption by Native people and the high fungus biodiversity, Ecuador is slowly developing large-scale mushroom production for retail trade. The production of the mass market began in the sixties of the past century. AMCESA and KENNET cultivated *A. bisporus* mushroom, the most common edible Mushroom in the Ecuadorian market [3].

Today, mushroom production and industrialization are mainly centered in Pichincha province (Figure 1). Ecuadorian consumer preferences have significantly influenced the international sales of the country's mushroom production. In 1968, Ecuador began cultivating mushrooms. Of the first harvest, which totaled about 45 tons, roughly 90% were exported, while the remainder was sold locally [43]. In Ecuador, the most cultivated species are the oyster mushroom (*P. ostreatus*), pink oyster mushroom (*P. djamor*), white Mushroom (*A. bisporus*) and shiitake (*L. edodes*). Most of the production is carried out by privates or through rural development projects sponsored by the government [44]. To our knowledge, little data is available about Ecuador's current edible mushroom market; the limited information is about dried mushrooms. Data revealed a clear growth trend in Ecuador's dried mushroom production from 2007 to 2015, with an average annual increase of 4%. However, there were fluctuations throughout this period. Production reached a high of USD 501.000 in 2014 but fell significantly the following year. This decline is reflected in the export figures 2015, which showed a substantial decrease compared to 2014, reaching USD 577.000. This represented a 35% decline from 2007.

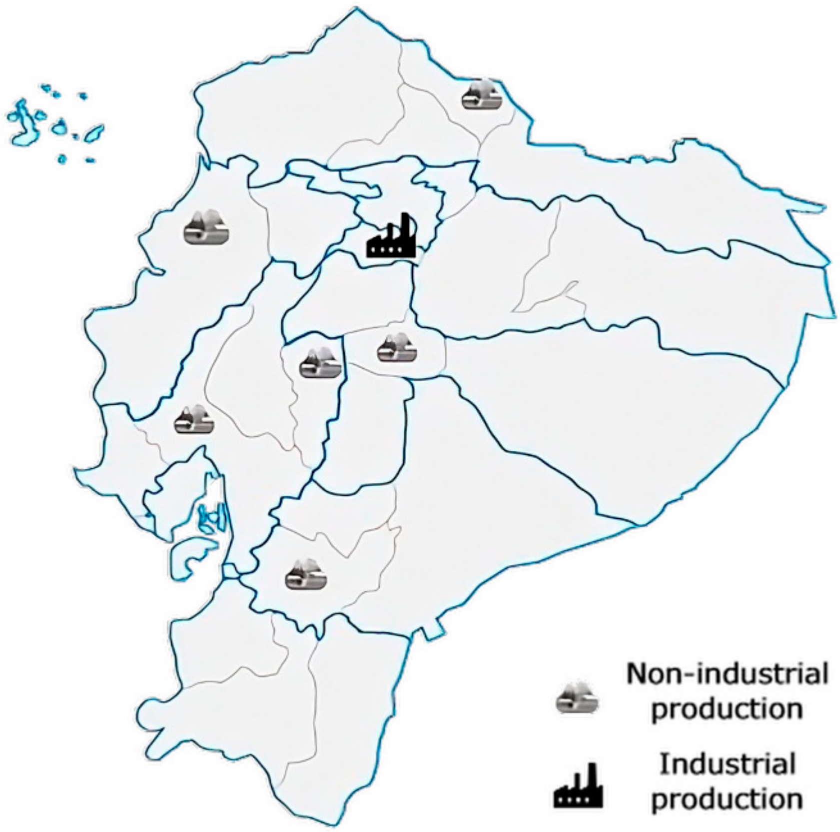


**Figure 1. Distribution of industrial and non-industrial production of edible mushrooms in Ecuador.**

In contrast, consumption of dried mushrooms rose considerably over the same period. In 2014, consumption peaked at USD 889.000 before falling dramatically in 2015 in terms of market value (USD 576.900) and production (25 tons). On the contrary, in 2007-2015, overall consumption steadily increased. Consumption reached a record high of 35 tons in 2014 before significantly dipping the following year. Despite a notable decline in revenue in 2015, the Ecuadorian dried mushroom industry experienced a growth in consumption leading up to that year [45].

According to a market analysis conducted in Quito to evaluate the potential selling of *P. ostreatus* as a source of fungal protein, it has been observed that people most interested in consuming edible mushrooms are those who take care of their physical health through good dietary practices and people with socio-environmental awareness. According to the National Institute of Statistics and Censuses of Ecuador, mushrooms are not considered in the basic food basket, costing USD 712.11 (January 2021). Thus, edible mushrooms are intended to be offered to consumers with an income above the basic food basket [46].

Moreover, in a recent study in Los Rios province of Ecuador, approx. The 77% of people involved in a study about mycophagy's state of the art indicated their interest in cultivating mushrooms [47]. A similar scenario was recorded in Cuenca (the regional capital city of the Andean province of Azuay), where 82% of inhabitants, aged between 15- and 74 years old, used to consume edible mushrooms in their diet [48]. Consumers' growing desire for healthy, eco-friendly products has driven demand for locally produced alternatives. This shift in dietary preferences presents a commercial opportunity for Ecuador to expand its cultivation of edible mushrooms [49].

**BIOTECHNOLOGICAL USE OF AGRICULTURAL BY-PRODUCTS IN ECUADOR: PRODUCTION OF EDIBLE MUSHROOMS**

Edible mushroom cultivation on lignocellulosic substrates dates back hundreds of years [50]. Substrate features influence cultivated mushrooms' chemical, functional, and sensory characteristics. Substrate decomposition is related to fungi's ability to secrete hydrolytic enzymes (cellulases, xylanases and tannases) and oxidase enzymes that degrade plant by-products [52]. Design and control of edible mushroom production is of great importance, as well as having food that preserves its nutritional value and is microbiologically safe. This process usually occurs indoors in small greenhouses and involves solid-state fermentation. This biomass can include different types of by-products from agro-industrial production [52]. From this perspective, coculture has become a prominent alternative. Fungi used in coculture are saprophytes, and thanks to lignocellulosic exoenzyme production, they act as converters of agricultural and forest waste biomass into carpophores, which are exploited as food [40]. The process includes several operations: *inoculum* preparation, substrate preparation, inoculation, production, and harvest. The *inoculum* consists of pure mycelium of a specific strain obtained from spores, mushroom pieces, or germplasm sell providers. The collected mycelium is transferred to cereal grains such as wheat, rice or rye to produce the propagation material known as "spawn." The substrate is previously selected according to particle size and the presence of pathology symptoms. The next step is pasteurization, which reduces biological contaminants that can disturb mushroom growth; it usually happens at 60 °C for 1-2 hours. After substrate cooling, inoculation is carried out using the spawn previously prepared by distributing the *inoculum* homogeneously into the cultivation substrate. Depending on the mushroom species, the cultivation techniques differ [53].

*Agaricus* mushrooms are grown on trays, using compost as the growing medium. The process happens in tunnels, which are unique fermentation rooms. Edible mushrooms grow on the compost surface and are cut and harvested at the mature stage. *Lentinus* is traditionally grown on wood logs, but in Ecuador, it has been replaced by artificial log cultivation, utilizing heat-treated substrates composed of sawdust enclosed in plastic bags, known as "bag-log cultivation." This approach offers shorter crop cycles and increased yields. *Pleurotus* is cultivated in polyethylene bags arranged in stacks on shelves or bag-suspended systems hooked on the ceiling. For *Lentinus* and *Pleurotus* production, after the incubation time, perforations on the bag edges are made to allow carpophores to grow outside and be harvested. Enhancing productivity in mushroom cultivation requires assessing a control system that monitors the environmental parameters in the growing rooms, such as temperature, relative humidity, airflow, oxygen and carbon dioxide content. In Ecuador, the harvest is made manually, and mushrooms are sold chiefly as fresh food; only a few producers transform them into pickled products [54].

Mushroom cultivation is a valuable alternative to use agricultural wastes and thus to reduce environmental pollution [5]. Many different types of agro-industrial wastes are used, both of plant and animal origin (Figure 2) [51,55-59].

Studies showed that mixing agro-industrial wastes can increase biological efficiency and Mushroom production compared to single-substrate cultivation. Different substrates have different cellulose, hemicellulose and lignin contents that contribute to the nutritional requirements of growing fungi [60,61]. In the Ecuadorian economic context, edible mushroom cultivation may become a sustainable strategy for the use of agricultural waste. The country's economy is mainly based on agricultural production, which generates large amounts of waste [62]. The most significant agricultural production is focused on permanent crops such as cocoa (*Theobroma cacao*), African palm (*Elaeis guineensis*), banana (*Musa paradisiaca*), sugar cane (*Saccharum officinarum*) and is spread over 1.42 million hectares. The cocoa area represents 41.8% of the total permanent crop area, implying a high production of by-products. Studies have shown that 80% of fruit is discarded, giving rise to by-products such as seed husk and fruit mesocarp [40]. Sugar cane (*S. officinarum*) is a relevant crop, too. The juice extraction process generates bagasse, the fibrous residual part of the stalk, as a by-product. Cellulose, hemicellulose, lignin, ash, and wax characterize its chemical composition. Bagasse represents approximately 30% of the plant's weight and is one of the most abundant agro-industrial wastes in the world, with an annual production of 1900 million tons. In Ecuador, approximately 8.6 million tonnes are produced annually, [63,64]. It is a versatile material that produces paper, biofuel, and animal feed. Due to its chemical composition and texture, it lends itself as a substrate for solid-state fermentation processes [63], such as mushroom production.

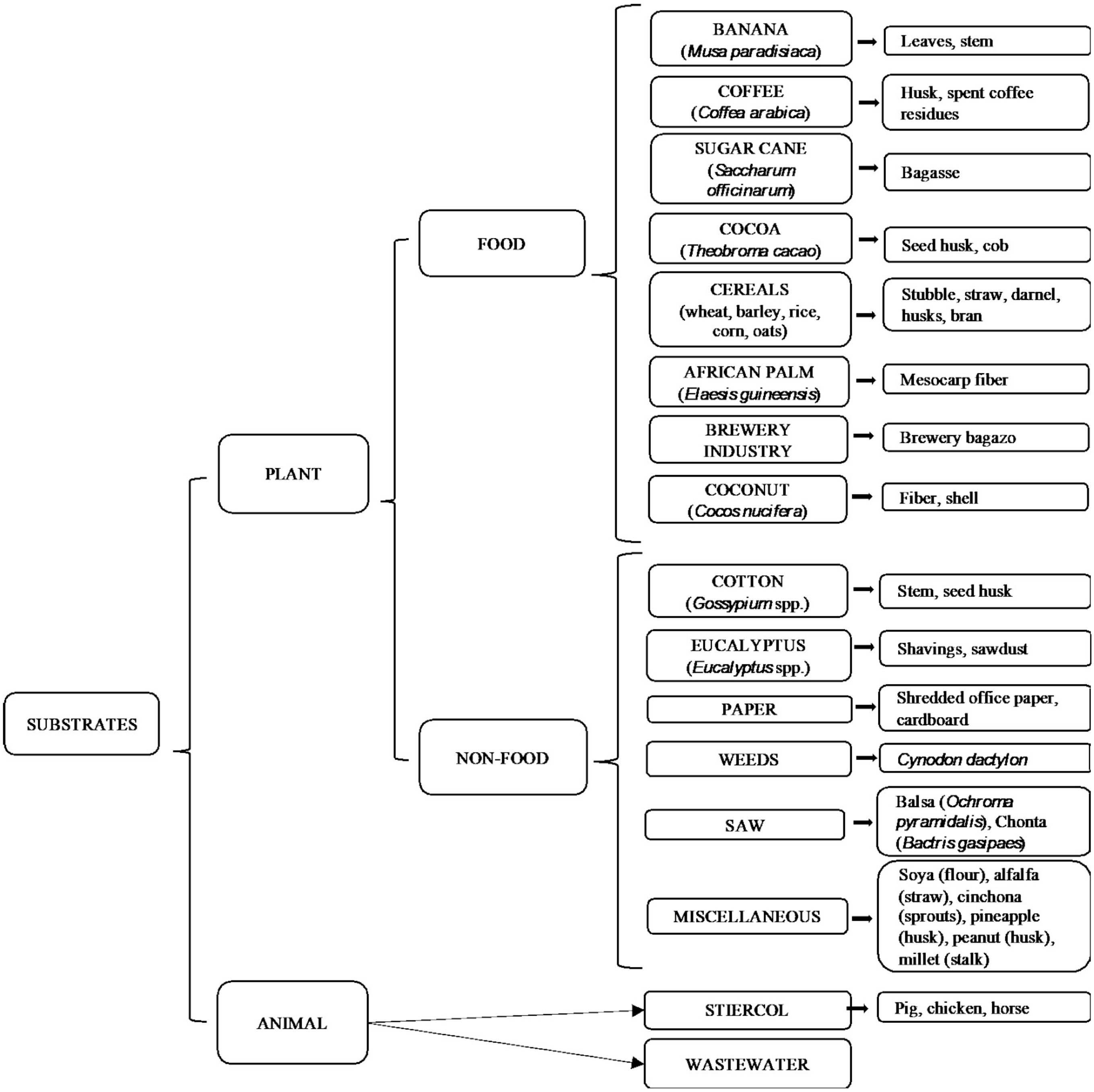


**Figure 2. Growing substrates available in Ecuador for edible mushroom production are obtained from plant and animal waste.**

Coconut palm (*Cocos nucifera*) is another permanent crop that is highly present in Ecuador. In 2019, total coconut production was 6.2 metric tons, with Manabí province contributing 1.8 metric tons. Farmers in Manabí use palm residues and trunk fiber as compost, while coconuts sold by small-scale traders are incinerated. In Manta, coconut waste generated by merchants and consumers is disposed of in municipal landfills, generating waste management problems [65,66].
The availability of agricultural by-products is an essential factor in planning the production of edible mushrooms; however, it is pivotal to consider their safety for human health. Studies have shown that *P. ostreatus*, *A. bisporus,* and *H. ercinaceus* mushrooms grown on mercury-containing substrates have accumulated

mercury in the carpophore and stem without altering the composition of macronutrients such as carbohydrates, proteins, and fats. These results demonstrate the fundamental role of selecting suitable growing substrates that avoid exposure to mercury levels harmful to human health [67].
Regarding economic feasibility, edible mushroom production in Ecuador using agricultural wastes recorded a lack of official data from governmental institutions, such as production costs and market prices. Experimental studies on local universities in the Azuay province showed that the production costs of fresh mushrooms fluctuated between USD 4.2/kg [68] to 6.8/kg [48], while market prices varied between USD 10/kg [48] to 26/kg [69]. These costs and prices mainly varied depending on the mushroom species and infrastructure availability. The Ecuadorian Ministry of Agriculture and Livestock (MAGAP) reported specific mushroom production experiences in the Amazonian region [70]. However, the Ecuadorian government considers the rural and agricultural sector a key driver of economic growth, prioritizing food production and developing long-term, sustainable activities that create jobs and income [71]. Government and non-governmental incentives are available for farmers who want to invest in small agriculture production, such as the Agrobiodiversity, Seed and Sustainable Agriculture Research Fund (FIASA) [72] and the Inter-American Development Bank (IDB) [73]. With these premises, edible mushroom production could become an opportunity for economic development in Ecuador, even in rural areas.

## CONCLUSIONS

Cultivated edible mushrooms are a source of protein low in fat and calories. Secondary metabolites such as polyphenols, lactones and other bioactive compounds increase their commercial value and interest in customers. Cultivated mushrooms are saprophytes; they grow on organic decomposing substrates, such as waste from agriculture and the paper industry. Ecuador is a country based on agriculture. In fact, after oil, agricultural exports like bananas, cocoa, and shrimp are the country's second-largest source of income. The production process generates tons of by-products that can be repurposed as growing substrates for edible mushrooms. Ecuador's abundant plant and animal waste and the potential for creating substrate mixtures provide the technical foundation for utilizing agricultural waste through coculture.
In addition, more studies are needed on the medicinal properties of the edible mushrooms considered in this review to gain a more comprehensive knowledge of their properties.
However, it is necessary to ensure that substrates are free of chemical or physical contaminants that mushrooms could carry during production. This literature review suggests further investigation into the following aspects: a) carry out experiments on new edible mushroom species using local agro-industrial wastes, b) identify promising native species for use in the agro-industrial sector, c) carry out studies on the presence of heavy metals or other undesirable compounds.

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