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Processes For The Transformation Of Fruit And Vegetable Residues For The Production Of Edible Mushrooms

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Abstract

The cultivation of edible mushrooms from fruit and vegetable residues presents itself as a promising solution for the sustainable utilization of these wastes and the production of nutritious food. Fruit and vegetable residues include crop residues, leaves, branches and unsold products, which contain a wide range of nutrients and bioactive compounds. These are used as substrate for the cultivation of edible mushrooms. Edible mushrooms, such as mushrooms, shiitake and pleurotus, are appreciated worldwide for their taste, texture and nutritional properties. They contain protein, fiber, vitamins, minerals and bioactive compounds with antioxidant, anti-cancer and anti-diabetic properties. In addition, the global market for edible mushrooms is experiencing significant growth due to their wide range of applications in the food, pharmaceutical and cosmetic industries. The method of cultivating edible mushrooms from fruit and vegetable waste involves the selection of suitable waste, its preparation by sterilization, addition of nutritional enrichment agents and inoculation of the desired mushroom. After a period of incubation and proper care, the mushrooms can be harvested and used in various food preparations. The cultivation of edible mushrooms by solid fermentation has great advantages, as it is the most efficient way of converting vegetable waste into high-value human food.

Keywords: *waste, fruit and vegetable, edible mushrooms, transformation processes.*

Introduction

Cuty et al. (2017) evidence that the annual production of organic matter derived from photosynthesis on Earth is massive, but most of this matter is converted into inedible waste that pollutes the environ[1]ment; Currently, the lack of economic, social and nutritional options to take advantage of agro-industrial waste has led to poor management and contamination of natural resources. It also underlines that environmental protection is essential for agribusinesses, not only for their economic performance, but also for their relationship with the environment, which makes the efficient and environmentally sound use of waste crucial due to legal restrictions in many countries Azul, A.M (2018).

Patiño (2014) defines biomass as material of biological origin, excluding mineralized materials and materials formed in geological formations; It includes waste from processes

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with biomass, such as agriculture, forestry, livestock, industry and municipalities, which contribute to the production and purification of energy.

Solid State Fermentation (FES) is a process where microorganisms grow in a solid material that serves as food and a growing environment; compared to another process called Submerged Fermentation (FEL), FES has advantages such as being cheaper, producing more, using less energy, being simpler, using less water, and recovering products better (Ortiz, 2016). The production process is divided into three steps: first, the base material is prepared; then, FES is carried out, allowing microorganisms to colonize it; finally, the products are collected, packaged, and stored for sale (Díaz, 2016).

Mushrooms are a valuable source of nutrition with little-known functional properties. They have antitumor, immunomodulatory, antioxidant, antimicrobial, antiviral, and other human health benefits due to their bioactive compounds (Fernández et al., 2020). In recent years, agricultural and agro-industrial residues of plant origin have been generated, which have a high content of cellulose, a glucose polymer, which is the main component of the cell wall of plants, so these residues are used for the cultivation of the fungus Pleurotus ostreatus, which presents as an option to take advantage of the available agricultural and agro-industrial lignocellulosic waste. This technique has been disseminated throughout different countries, due to the abundance of the raw material for its development, due to the fact that it uses cellulose and lignin present in these wastes as its main food. (Diaz, and Others, 2019)

Fruit and vegetable residues

Fruit and vegetable residues are the organic waste generated during the cultivation, processing and marketing of fruits and vegetables; these residues can include crop residues, leaves, branches, inedible parts of plants, production leftovers and unsold products (Ministry of Environment and Sustainable Development of the Republic of Argentina, 2016). Proper management of fruit and vegetable waste is important to avoid negative environmental impacts and can have added value if it is recycled or reused in other activities, such as the production of compost or its use as animal feed. (National Commission for the Environment, 2003)

Physical Characterization

Fruit and vegetable residues include organic materials that arise at different stages of the production, processing and sale of fruits and vegetables, these wastes include crop residues, leaves, branches, inedible parts of plants and surplus production or non-marketed products (Ministry of Agriculture, Livestock and Fisheries of the Nation, 2020). The physical characteristics of fruit and vegetable residues are detailed below:

a) Shape and size: Most agricultural products have similarity in geometric bodies (sphere, cone), which is what determines volume and density. (Blue, 2018)
b) Surface area: it is a very useful feature in heat transfer processes, such as dehydration, pre-cooling and refrigeration, and also in the evaluation of the physical quality of agricultural products. It is determined by measuring the area of the peel or epidermis of the product, removing it in the form of strips and drawing it on paper and then reproducing the total area of the product by planimetry (Acosta, 2018).
c) Volume: indispensable in the post-harvest, it influences the packaging and storage of products. This is measured by placing it in an appropriate container. (Krysa, 2018).
d) Density: The ratio of the weight, mass, and volume of the product. (Cury, 2015).
e) Porosity: Indicates empty spaces left by products between each other. (Liguori, 2017)

$$Porosidad = 1 - \frac{Densidad\ aparente}{Densidad\ real} x100\%$$

f) Visual: size, shape, brightness, color and absence of visual defects are important. (Messina, 2019).

Composition and properties of Fruit and vegetable residues

According to a study by Liguori et al. (2018), fruit and vegetable residues are mainly composed of cellulose, hemicellulose, lignin and pectin; These residues also contain a large amount of nutrients, such as nitrogen, phosphorus, potassium and other trace elements, as a result, fruit and vegetable residues have the potential to be used as a source for the production of bioenergy, fertilizers and other value-added products. In addition, studies have revealed antioxidant properties in some fruit and vegetable residues. For example, a study by Zandonadi et al. (2018) found a high antioxidant capacity in acerola residue, suggesting that it may be an important source of natural antioxidants.

Pre-treatment and treatment of fruit and vegetable residues to obtain mushrooms

Fruit and vegetable residues must undergo a previous treatment in order to reduce the microbial load as much as possible, there are different methods, the three main and most used, autoclave sterilization, pasteurization and lime treatment, it is necessary to work with substrates that do not present obvious characteristics of contamination (fungi, yeasts, bacteria and/or pests). (Rubio et al., 2021). The fruit and vegetable waste complex is made up of a matrix of cellulose and lignin carbohydrates intertwined by hemicellulose chains, this structure offers great resistance to attack by microorganisms, which is why it is a factor that affects the productivity of the process. (Pineda & Beltrán, 2014)

Pretreatments can be physical and chemical, enzymatic, or a combination of all. According to Abril and Balat, the ideal pretreatment of these materials consists of achieving reactive fibers, separating the pentose without degrading them, not generating compounds that inhibit fermentation and not requiring a drastic reduction in particle size.

(Alexander, 2018)

Edible mushrooms from fruit and vegetable residues

Fungi from fruit and vegetable residues are organisms of the kingdom Fungi that can be produced using fruit and vegetable waste (Oei, 2013). According to Nieto (2013), fractions enriched in dietary fiber can be obtained from fruit and vegetable residues; These residues provide the organic matter necessary for the growth and development of fungi.

Román (2013) mentions that vegetable waste can also be used in the production of compost, which shows that fungi can be produced using different types of fruit and vegetable waste, which contributes to the valorization of this waste and the obtaining of products of nutritional interest.

Value nutritional of the Edible mushrooms

Mushrooms are an important source of nutrients and bioactive compounds. A recent study conducted in China found that edible mushrooms contain a wide variety of essential nutrients, including protein, fiber, vitamins, and minerals (Wu et al., 2018). In addition, some mushrooms have been found to contain bioactive compounds that have antioxidant, anti-cancer, and anti-diabetic properties (Guo et al., 2019). Another study conducted in Mexico found that edible mushrooms have a nutritional composition similar to that of other dietary sources of protein, fiber, and minerals. In addition, some mushrooms contain compounds such as ergosterol that can be converted into vitamin D by exposure to ultraviolet light (Diaz et al., 2018).

Types of bioreactors for FES

The production of biomass of edible mushrooms from their fruiting body is based on the FES process, in general these equipment are static or dynamic fermentation, within static fermenters there are tray and static bed fermenters and within the agitated fermenters are the tunnel fermenters, the rotary disc, the rotary drum, the tank with agitation and the continuous screw type.

(Cela, 2019)

Considering that the growth of the biomass of the fruiting body takes place outside the growth cell of the mycelium, that is, in an aerial way, the most recommended fermenters will be the static ones, in the literature five types of fermenters for the production of Pleurotus by FES are reported: fixed ridge-type beds, beds on shelves or trays, in bottles. (Diaz, 2020)

Methodology Process of production of edible mushrooms from waste
Preparation of the growing medium
Regarding the conditions and parameters of the cultivation of mushrooms obtained from fruit and vegetable residues, the following details are presented:

a) **Temperature:** In the incubation stage the optimal temperature is kept around 20-24°C, during the fruiting period, lowering the temperature slightly, around 16-18°C, will favor the formation of fruiting bodies. (Mezhericher, 2019).
b) **Relative humidity:** It is important to maintain a high relative humidity (around 85-95%) to promote fungal growth, this can be achieved by spraying water regularly and using a misting system (Patiño, 2014).
c) **Ventilation:** Proper air circulation is an essential element in providing oxygen to fungi and removing accumulated carbon dioxide. A constant and smooth circulation of air can be achieved by implementing an adequate ventilation system (Fajardo, 2001).
d) **pH of the growing medium:** The optimal pH range is around 5.5-7.0. This condition can be achieved by carefully regulating the components of the substrate and, if necessary, adjusting the pH by incorporating acidic or alkaline solutions (Hernandez, 2019).
e) **Inoculation density:** The density of inoculated spores or mycelium may vary, but it has been observed that an adequate range is approximately 5-10% in relation to the total weight of the substrate (Sánchez & Royse, 2001).

Fruit and vegetable waste is fermented to serve as support and nourishment for the mycelium in the case of the bulging of coffee or sugarcane pulp; in the case of chopped stubble or corn cobs; hydrated, dried, pasteurized and refrigerated. If necessary, the substrate can be conditioned by adding chopped hay, maize meal, sorghum hops, sunflower meal, dehydrated alfalfa and rice bran. (Castellanos, 2008)
The pasteurization of fruit and vegetable residues is generally carried out by immersion in cold or hot alkaline water seeking to eliminate the microorganisms present, another method of pasteurization consists of immersing the substrate in water at 80ºC and maintaining for 40 minutes, in the same way the pH of the substrate will be conditioned with the addition of calcium carbonate until it reaches a value of 6.5-7. (Rodríguez & Pardo, 2021).

Sowing
In transparent and new bags, layers of substrate and seed are manually interspersed, trying to make the mixture uniform and avoiding leaving uncovered areas. the substrate Must be previously sterilized or pasteurized, drained and at a temperature below 30° C (Rodríguez, 2017). In inoculation with the seed-mycelium mixture, alternating layers with 100 g of mycelium-seed from 4 to 7 kg of substrate are added, and the bag containing this mixture is closed by removing the air inside. (Castellanos, 2008)

Incubation
Incubation is a process in which the mycelium of the fungus covers the entire substrate and lasts: 20-30 days at 70% humidity, at a temperature of 25-28 °C and in complete darkness to avoid draughts (Grass, 2019). At this stage, special attention should be paid to the color and smell of the bags and discard them in poor condition, a Girgolas bag should be covered with white mycelium similar to cotton; Any other color (green, yellow, pink) indicates the presence of contamination and should be strictly excluded. (Pérez, 2021)

Induction

When the incubation process is completed, induction occurs, the purpose of which at this time is to stimulate the formation of reproductive structures, which requires the mycelium to undergo changes in environmental conditions (stress induction), such as an increase in the photoperiod, a decrease in the photoperiod and changes in temperature (15 – 18°C) with a percentage of CO_2 and O_2 gases (carbon dioxide and oxygen). (Mezhericher, 2019)

Fruiting

During this process, the reproductive structure or fruiting body is formed, which is the edible part, colloquially called

"mushroom." Conditions: Humidity 85 – 95%, temperature 18 – 22 °C, ideal pH value of the substrate between 6.5-7, humidity of the substrate 50%, variable light/dark cycle 12 hours, air change of 4 to 1 hour per hour 6 times when it is necessary to check for the presence of pests such as flies, rodents and insects that can cause losses in production or reduce the final quality of the product. (Castellanos, 2008)

Harvest

Harvesting is done by hand using a very sharp, clean and sterilized knife to cut the fruiting bodies (CFs) as close to the surface of the substrate as possible. The mushrooms are done when the cap looks compact, puffy, not extended, or limp, before its edges are rolled up. (Patiño, 2014) The first harvest can last between 1 to 3 days, leaving the smaller mushrooms for the next cut that is made one to two weeks later, 3 to 4 waves of mushrooms can be expected, with the production of each of them being less and less. (Grass, 2019)

Conservation

Storage methods can keep mushrooms fresh or as a value-added product, the most commonly used preservation method today is the use of plastic bags to freeze at 4°C, and it has given good results, this method keeps the mushrooms in optimal condition, the fresh state guarantees a shelf life of up to 10 days and is also kept by controlling the atmosphere around the mushrooms in special chambers, where the amount of oxygen and carbon dioxide and the gases used inhibit the respiration of the fungi and with it their senescence. (López, 2019) Other methods cause more changes in the fungus tissue, but mostly retain their sensory properties. These methods are: freezing, dehydration and canning (Fajardo, 2001).

Control of the fermentation process (mushroom culture)

The moisture and water activity percentage in solid fermentations can vary from 30% to 80%, depending on the solids used, the microorganisms, and the process objectives (product formation, biomass growth), Although the moisture percentage is one of the commonly optimized variables in solid fermentation systems, It is now recognized that not only the amount of water in the system affects the efficiency of the process, but also the interaction between the inherent water and the solid medium. (Domínguez, 2018). That is why it is not contradictory to observe that the same microorganism fully develops in two different substrates with a percentage of

humidity quite dissimilar. (Toledo, 2008) **pH**

pH is another variable that affects the development of solid-state fermentation processes, just as it does in submerged cultures, however, in the case of solid fermentation, its control is practically impossible, due to the absence of instruments capable of measuring the pH in the liquid layer that surrounds the solid. On the other hand, the mixing of solids is a complex process, which is why it is also difficult to control this variable during the development of fermentation. (Almendez, 2017)

The pH changes for different reasons; it is normally lowered by the secretion of organic acids such as acetic and lactic acids during the process. However, the source of nitrogen used has a strong influence on the pH trend. (Armijo, 2017) **Temperature**

In solid fermentation, temperature is the variable whose control is considered most critical due to the high concentration of substrate per unit volume and the low fermentation temperature, the thermal conductivity of heterogeneous solid-liquid and gaseous systems is favorable to the accumulation of metabolic heat in the system and increase in culture temperature. (Fabricio, 2015)

Temperature control has been addressed using both traditional and non-traditional methods of heat removal. Traditional methods involve heat exchange through conduction and forced convection mechanisms. (Gonzales, 2015)

The concentration and availability of the substrate

The growth medium must contain a balance of all the necessary nutrients, in order to promote the growth of microorganisms, the relationship between some of its elements, such as carbon-nitrogen and phosphorus-oxygen, is particularly important, the latter is related to the efficiency of energy conversion and respiration, the composition of the medium and quantitative aspects, In other words, it is necessary to determine the concentration of each component to be used, because in submerged culture the concentration of the substrate affects the development of the fungus. (López, 2003).

Aeration

Aeration is used to supply the necessary oxygen, to extract the formed CO2, as well as to extract the evolved metabolic heat, so that the optimal airflow must take into consideration the nature of the microorganism used, the oxygen requirements for growth and/or the formation of the desired product, the rate of metabolic heat generation, the critical concentration of carbon dioxide and other volatile metabolites, the thickness of the solid mass, among others. (Agudelo Chaparro, 2014) Aeration in FES is easier than submerged fermentations, because the contact surface is larger between the air and the liquid that is absorbed in the particles. (Cordero, 2013) Solid **State Fermentation (FES) Solid** state fermentation is a technique that is used for the production of enzymes and other metabolic products from fruit and vegetable residues, this technique is carried out in a solid medium with no or very little amount of water in the case of fungi, fruit and vegetable residues can be used for the production of enzymes and other products, solid-state fermentation of mushrooms can be a sustainable alternative for the recovery of waste and the production of high value-added products (Domínguez, 2018).

Results and discussion Mushroom quality control Productivity parameters

In order to know the production potential of the studied strains, the biological efficiency (BE) and the production rate were determined. (i) biological efficiency (BS) is determined by expressing as a percentage the ratio of the fresh weight of the mushrooms produced to the weight of the dry substrate [EB (%) = (weight of fresh mushrooms / weight of dry substrate) *100%]; and (ii) the production rate (TP) is determined by the ratio of the percentage of biological efficiency to the total number of process days [TP= EB (%)/number of process days. (Vega & Franco, 2013)

Table 1. Operating parameters in the production of edible mushrooms.

Species	Particle (mm)	pH	Humidity of the substrate (%)	Temperature (°C)	Relative humidity (%)	Light (lux)

P. ostreatus	20, (14,147,6); (1,52,0); (0,921,68); (30-50)	5,5	70; (70-80); (60-70)	25; (20-28); (18-25); (7-34); 30; (25-30)	70; (7590); 80; (31100); (8690); (80-92)	(15-135); (2050) (80-100); (100-200); 900 (400800)
						(1500-2000)
P. eryngii				25		(80-100)
P. sajor-Caju	(47,6-14,1); (50-100)	5,5; (6,5-7)	(70-80); (70-72)	25 (20-25)	85	(15-135) 60
P. pulmonarius						
P. sapidus						(15-135)
P. cornucopiae	(50-100)	(6,5-7)	(70-72)	(20-25)	85	

Source: (Pineda & Beltrán, 2014) Shows the operating parameters in the production of edible mushrooms.

Size of fruiting bodies (fungi) To determine the size of the fruiting body, each bag is collected separately, the mushrooms should be measured and sorted according to the following format: A: mushrooms smaller than 5 cm, B: mushrooms 5-10 cm, C: mushrooms larger than 10 cm. The total number of fruiting bodies harvested per bag should be sorted by size and weighed.
(Chiriboga et al., 2015).

Nutritional analysis
The mushrooms of each of the strains must be harvested and dried at 65ºC, ground and sifted to 20 mesh; The sifted mushrooms must be mixed to obtain a composite sample of each strain-substrate combination, using the quartering process. These samples will be stored in ziploc bags and kept at 10ºC, until they are subjected to analysis using the official methodology (AOAC, 2005). (Rodríguez, 2018) The parameters analyzed can be: crude protein, crude fat, crude fiber. Each sample is analyzed in triplicate and using one gram of sample in each case (Martínez, 2018).

Table 2. Nutritional value of edible mushrooms.

NThis is the	**Per 100 gr**	**Daily Value**
Energy	38 kcal	2 %
Total Fat	-	-
Carbohydrate	6,9 gr	2 %
Cholesterol	Mg	%
Sodium	9 mg	1 %
Water	89.85 mg	89 %
Protein	1.49 g	2 %
VITAMINS		
Vitamin d	5.30 mg	53 %
Vitamin B-3	4.1 mg	20 %
Vitamin B-5	1.07 mg	11 %
Vitamin B-9	2 mg	1 %
MINERALS		
Calcium	15 mg	2 %
Iron	3.47 mg	19 %
Potassium	506 mg	11 %
Phosphorus	57 mg	6 %
Sodium	9 mg	1 %

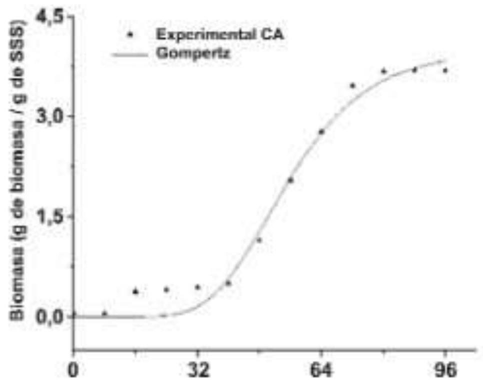
Source: (Molina, 2012)

It shows the nutritional components of mushrooms.

Statistical analysis

All results can be analyzed using ANOVA and Tukey tests to determine the statistical significance between the different strains, substrates and their interaction (López, 2007).

Figure 1. Fermentation time in days.



Rosero and Duster (2017) show us the growth kinetics of Auricularia auricula UTM-aa-b033112 on sugarcane bagasse. Temperature 27.4 °C, initial humidity 65%, initial pH 4.5 and luminous intensity 500 Lux.

Conclusions

A large amount of organic matter is produced annually in the world through photosynthesis, but most of the organic matter is converted into inedible waste, causing environmental pollution. It is important to find economic, social and nutritional alternatives to take advantage of this waste and avoid its mismanagement and the contamination of natural resources.

Environmental protection is becoming increasingly important for agricultural businesses, not only for its economic benefits, but also for its environmental impact. Due to regulatory constraints in many countries, the efficient, economical and environmentally safe use of agricultural and fruit and vegetable waste has become essential.

Edible mushrooms are a valuable source of nutrients, but their functional properties are not well understood and their bioactive compounds, such as their anti-tumor, immunomodulatory, antioxidant, and antibacterial properties, may benefit human health. Moreover, the global edible mushroom market is witnessing significant growth due to its various applications in the food, pharmaceutical, and cosmetic industries.

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