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# Assessment of the environmental impacts generated by cocoa cultivation biomass in edible mushroom fruiting

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**Abstract**

Based on a bibliographic review of articles and scientific documents regarding the composition of cocoa pod husk (CPH), the benefits of its use as a substrate, and the parameters required for the production of edible mushrooms, an environmental assessment for the operation phase was conducted. A total of 85 environmental aspects were identified, along with 85 direct impacts and 117 indirect impacts related to various environmental components. However, after reviewing the entire project phase, the environmental impacts were reduced to 38. Additionally, the utilization of CPH generates employment and economic income for the community, although it requires high consumption of water, energy, and fuel. The environmental categorization of the project indicated that it is a moderate-impact project, where its effects do not spread beyond the direct area of influence.



*Keywords*: Cocoa, CPH, Substrate, Pleurotus, Edible mushrooms

## 1. Introduction

The main cocoa producers with a production contribution of almost 90% are Ivory Coast, Ghana, Indonesia, Ecuador, Cameroon, Nigeria, and Brazil [1]. In this sense, in the period of 2018/2019, the world production of this bean was approximately 4.7 million tons [2], taking into account that solid waste is generated as part of the process of obtaining cocoa beans, among which are the cocoa pod shell (CPH), a by-product of the cocoa dehulling process, which represents 70 to 80% of the dry weight of the whole fruit [3], [4], [5]. This year, 47 tons were produced of CPH, that is, each ton of dry cocoa beans generates 10 tons of waste [6].

On the other hand, this by-product (CPH) degrades in cocoa plantations, becoming a threat to the crop by generating pests such as Moniliasis, known as black pod disease, insect-induced perforations, and environmental impacts [7], [8], [9]. Similarly, in the document produced by [10], the biochemical composition of CPH is shown, primarily consisting of complex structures such as lignin (24.16%), cellulose (24.16%), and hemicellulose (16.75%), demonstrating a rich lignocellulosic composition of this biomass. On the other hand, to decompose these complex structures, Pleurotus fungi have been used due to their ability to utilize various materials as substrates [6], [11], [12], [13]. As saprotrophs, they extract their nutrients from the substrate but require specific conditions for preparation, inoculation, incubation, and production [14], [15] in addition to controlling factors for their fructification. Thus, in the study conducted by [7], the behavior of fungal species that colonize cacao plants, decompose and produce bioactive compounds is demonstrated, representing an alternative in bioconversion processes using CPH. This, in turn, results in environmental impacts that need to be assessed in each of the activities carried out within the process.

Based on the above, a systematic search for information on CPH (cacao pod husk) as a substrate for the reuse and utilization of this by-product in the cultivation of edible mushrooms was conducted. An assessment of the environmental impacts generated by such projects was performed, covering the entire production process of oyster mushrooms, from the collection of CPH by-products to packaging and preparation for commercialization.

## 2. Research method

### 2.1. Literature review

A systematic search for information from articles and scientific documents in databases such as Web of Science and Science Direct was conducted, utilizing keyword selection and search equations such as *pollution AND cocoa* (Figure 1) and *Mushroom AND production AND pleurotus AND waste* (Figure 2).

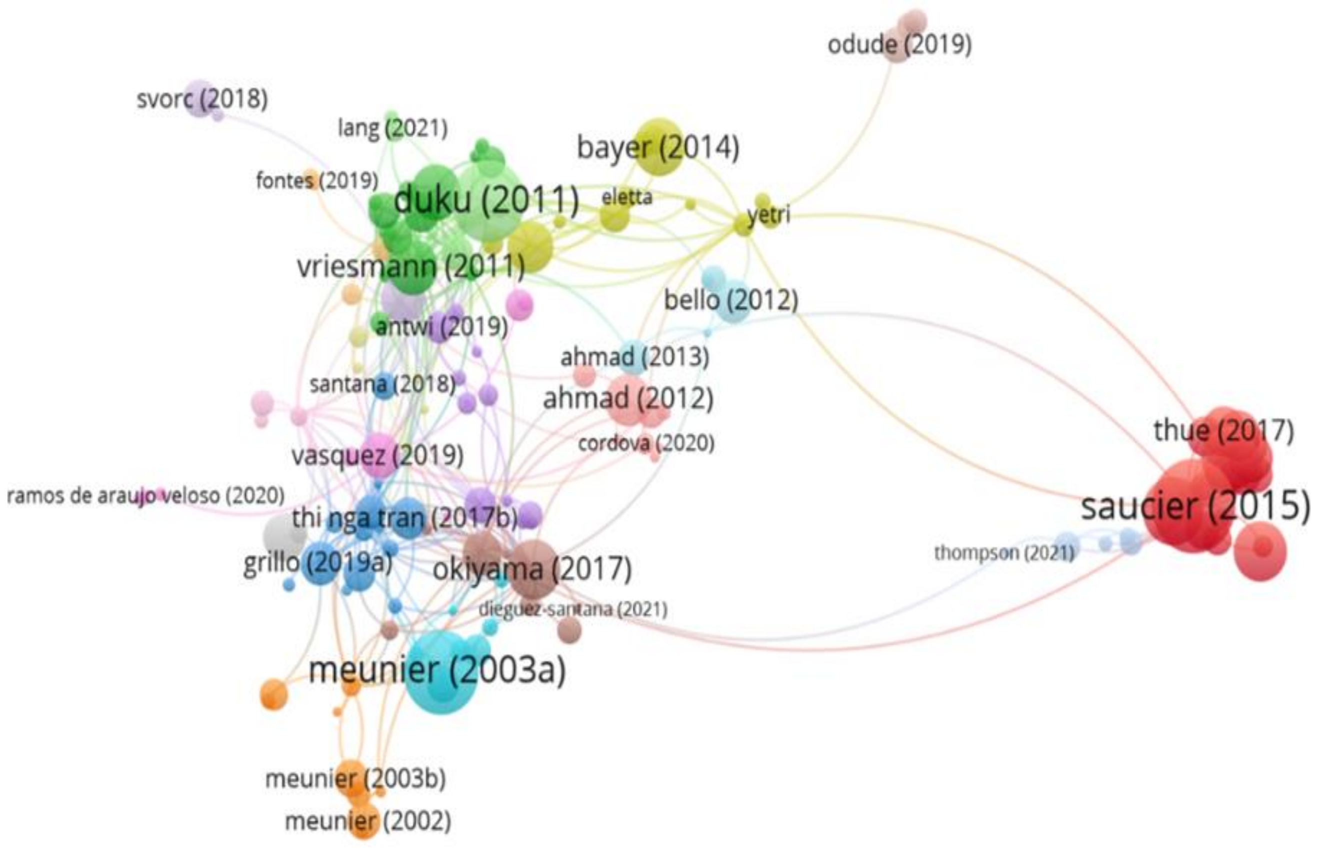


Figure 1. Top authors obtained from the contamination and cocoa search equation. Source: Author

These search strategies led to the construction of bibliographic networks using VOSviewer software, which was related to the principal cited authors and focused on CPH, along with the cultivation of edible mushrooms.

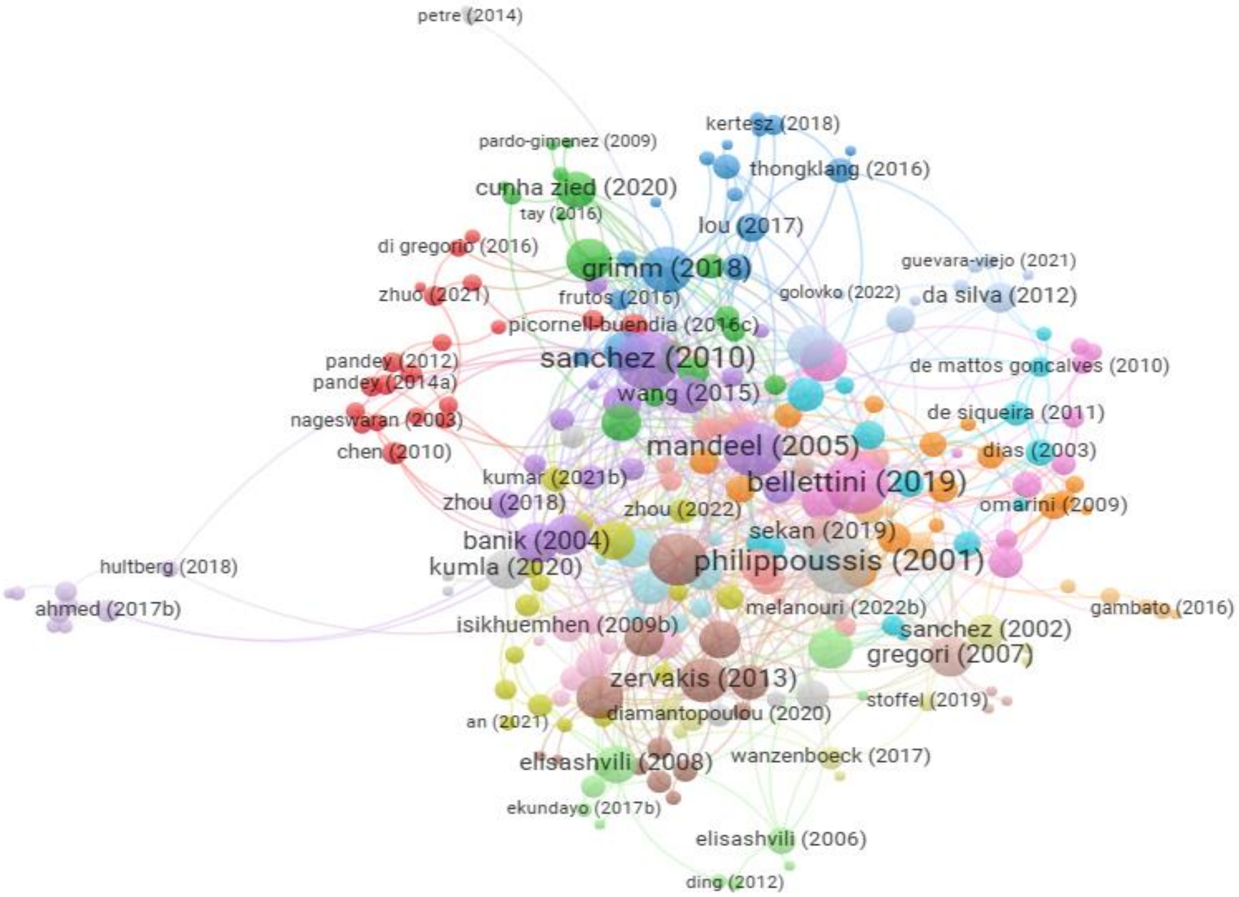


Figure 2. The main authors obtained from the search equation Mushroom AND production AND pleurotus AND waste. Source: Author

## 2.2. Assessment of environmental impacts

For the assessment of environmental impacts, the project's operational stage was considered for the treatment of CPH biomass as a substrate for mushroom cultivation, divided into five (5) phases: area conditioning, substrate management, mushroom harvesting, post-harvest activities, and management activities, including administrative management. Within these phases, activities susceptible to producing impacts (ASPI) were identified along with their respective environmental aspects. These impacts were evaluated using the EPM-Arboleda method [16] through Equation 1. It is noteworthy that for each ASPI, a detailed description was provided in response to two fundamental questions: What does the activity consist of? How will the activity be carried out? Based on these answers, the environmental aspects were constructed.

$$Ca = P[7{,}0 \text{ x } Ev \text{ x } M + 3{,}0 \text{ x } D] \quad (1)$$

Where: *Ca* corresponds to the impact rating, *P* is the presence, *Ev* represents the evolution, *M* is related to the magnitude, and *D* is the duration, which were assessed as shown in Table 2.

Table 1. Evaluation of the criteria used by the method [16]

| Criterion | Range | Value |
|---|---|---|
| Class (*C*) | Positive | + |
| | Negative | - |
| Presence (*P*) | Certain | 1,0 |
| | Highly Likely | 0,7 < 0,99 |
| | Likely | 0,4 < 0,69 |
| | Unlikely | 0,01< 0,19 |
| Duration (*D*) | Very Long: > 10 years | 1,0 |

| Criterion | Range | Value |
|---|---|---|
| | Long: > 7 years | 0,7 < 0,99 |
| | Medium: > 4 years | 0,4 < 0,69 |
| | Short: > 1 year | 0,2 < 0,39 |
| | Very Short: < 1 year | 0,01 < 0,19 |
| | Very Rapid: < 1 month | 1,0 |
| | Rapid: < 12 months | 0,7 < 0,99 |
| Evolution (*E*) | Medium: < 18 months | 0,4 < 0,69 |
| | Slow: < 24 months | 0,2 < 0,39 |
| | Very Slow: > 24 months | 0,01 < 0,19 |
| | Very High: > 80% | 1,0 |
| | High: 60% - 80% | 0,7 < 0,99 |
| Magnitude (*M*) | Medium: 40% - 60% | 0,4 < 0,69 |
| | Low: 20% - 40% | 0,2 < 0,39 |
| | Very Low: < 20% | 0,01 < 0,19 |

Thus, once the ratings for each criterion were established individually, the importance of the impact was determined, as presented in Table 2.

Table 2. Rating and importance of environmental impact, EPM methodology [16]

| Environmental Rating | Environmental Impact Significance | Abbreviation |
|---|---|---|
| ≤ 2,5 | Minor or Irrelevant | *I* |
| > 2,5 y ≤ 5,0 | Moderate | *M* |
| > 5,0 y ≤ 7,5 | Significant | *S* |
| > 7,5 | Very Significant | *Vs* |

On the other hand, through the application of Equation 2, the environmental categorization of the project (CA) was carried out to quantify the overall impact of the project.

$$CA = \frac{(NMs\ X\ 5) + (Ns\ x\ 4) + (Nm\ x\ 2) + (Ni\ x\ 1)}{Nt} \qquad (2)$$

Where *CA* represents the environmental rating of the project, *NMs* corresponds to the number of very significant impacts, *Ns* is the number of significant impacts, *Nm* is related to the number of moderate impacts, *Ni* is the number of irrelevant impacts, and *Nt* is the total number of impacts evaluated. Thus, with the *CA* value, the environmental categorization of the project could be (Table *3*):

Table 3. Environmental categorization of the project [16]

| Environmental Rating | Environmental Impact Significance |
|---|---|
| 1,0 – 1,99 | Low Impact Projects |
| 2,0 – 3,49 | Medium Impact Projects |
| 3,5 – 5,0 | High Impact Projects |

## 3. Results and discussion

The results of the assessment of environmental impacts generated by the use of CPH as a substrate for mushroom cultivation, within the process of producing oyster mushrooms during the Operation stage, broken down into the phases: Area Conditioning, Substrate Management, Mushroom Harvesting, Post-Harvest Activities, Management Activities, and Administrative Management (Table 4), identified 16 ASPI related to: Structure Erection, Collection and Transport of CPH By-Product, CPH Conditioning, By-Product Pasteurization, Seed Production, Mycelium Planting, Bag Dissection, Incubation, Fruiting, Mushroom Harvesting, Packaging and Packing, Storage, Disposal of Harvest Residues, Storage of Raw Materials and Other Inputs, Vehicle, Machinery, and Equipment Mobilization, and Personnel Hiring and Training. Based on the above, 85 environmental aspects were established, as well as 85 direct impacts and 117 indirect impacts related to various environmental components (Table 4). However, after reviewing the entire project stage, the environmental impacts were reduced to 38, which were assessed using the EPM-Arboleda method.

Table 4. Determination of components, ASPI, and environmental aspects for the operation stage

| Phase | ASPI | Description of ASPI | Environmental Aspects | Impacts | |
|---|---|---|---|---|---|
| | | | | Direct Impacts | Indirect Impacts |
| Area Conditioning | Structure Erection | For the edible mushroom production facility, areas required include: laboratory, inoculum preparation room, inoculum incubation room, substrate treatment area, pasteurization tunnel, substrate inoculation room, greenhouses, packaging room, and storage. This requires the use of machinery [17]. | • Formation of Artificial Elements in the Landscape<br>• Generation of Construction Waste<br>• Generation of Gases<br>• Generation of Particulate Matter<br>• Generation of Noise<br>• Impact on Site Vegetation Cover<br>• Fuel Consumption<br>• Water Consumption | a. Loss of Visual Quality of the Landscape<br>b. Increase in Construction Waste<br>c. Atmospheric Pollution from Gases<br>d. Atmospheric Pollution from Particulate Matter<br>e. Noise Pollution<br>f. Loss of Soil Vegetation Cover<br>g. Increased Fuel Consumption<br>h. Increased Water Consumption | a1. Ecosystem Degradation<br>a2. Loss of Habitat<br>b1. Increased Soil Erosion<br>c1. Increased Respiratory Diseases<br>d1. Increased Respiratory Diseases<br>e1. Community nuisance<br>f1. Soil Deterioration<br>g1. Atmospheric Pollution from Gases<br>h1. Decrease in Water Flow |
| Substrate Management | Collection and Transport of CPH By-Product | For the collection of biomass and the transport of CPH by-products from the harvest site to the production facility, sacks and manual tools such as shovels and wheelbarrows are required, depending on the amount of waste being transported. On a larger scale, additional machinery will be necessary for transportation. | • Impact on Visual Quality of the Landscape<br>• Utilization of Organic Waste<br>• Impact on Groundwater Quality<br>• Generation of Gases<br>• Generation of Particulate Matter<br>• Generation of Noise<br>• Impact on Site Plant Formations<br>• Fuel Consumption | a. Improvement of Visual Quality of the Landscape<br>b. Reduction of Organic Waste<br>c. Increase in Groundwater Quality<br>d. Atmospheric Pollution from Gases<br>e. Atmospheric Pollution from Particulate Matter<br>f. Noise Pollution<br>g. Increase in Soil Vegetation Cover<br>h. Increase in Fuel Consumption | a1. Ecosystem Improvement<br>a2. Habitat Recovery<br>b1. Recovery of Soil Porosity and Structure<br>b2. Modification of Microbial Activity<br>b3. Reduction of Vectors<br>c1. Improvement of Biochemical Oxygen Demand (BOD) in Groundwater<br>d1. Increased Respiratory Diseases<br>d2. Generation of $CO_2$ Greenhouse Gas Emissions<br>e1. Increased Respiratory Diseases<br>f1. Community nuisance<br>g1. Improvement of Plant Formations<br>h1. Atmospheric Pollution from Gases |
| | Conditioning of CPH | The biomass used as a substrate requires specific conditions for optimal mushroom development. A moist substrate with particles of the required size must be provided, additives are added to supply essential minerals, and then the substrate is mixed for 3 days. Then the substrate is piled into mounds. It must be homogeneous before it is subjected to a pasteurization process [18]. | • Generation of Organic Waste<br>• Impact on Groundwater<br>• Generation of Gases<br>• Generation of Odors<br>• Generation of Noise<br>• Water Consumption<br>• Energy Consumption | a. Increase in Organic Waste<br>b. Loss of Groundwater Quality<br>c. Atmospheric Pollution from Gases<br>d. Increase in Offensive Odors<br>e. Noise Pollution<br>f. Increased Water Consumption<br>g. Increased Energy Consumption | a1. Soil Erosion Generation<br>b1. Impact on Biochemical Oxygen Demand (BOD) in Groundwater<br>c1. Increase in Respiratory Diseases<br>c2. Generation of $CO_2$ Greenhouse Gas Emissions<br>d1. Community nuisance<br>e1. Community nuisance<br>f1. Decrease in Water Flow<br>g1. Impact of Greenhouse Gases |

| Phase | ASPI | Description of ASPI | Environmental Aspects | Impacts | |
|---|---|---|---|---|---|
| | | | | Direct Impacts | Indirect Impacts |
| | Pasteurization | Pasteurization is carried out by injecting steam using burners. The substrate is unloaded for sterilization to eliminate all undesired microorganisms, and it undergoes thermal treatment at 75–100°C for 4–10 hours. In this area, a table with features that facilitate washing and disinfection is required, with minimal air currents to prevent substrate contamination [17]. | • Generation of Organic Waste<br>• Impact on Groundwater<br>• Generation of Gases<br>• Water Consumption<br>• Energy Consumption | a. Increase in Organic Waste<br>b. Loss of Groundwater Quality<br>c. Atmospheric Pollution from Gases<br>d. Increase in Water Consumption<br>e. Increase in Energy Consumption | a1. Soil Erosion Generation<br>b1. Impact on Biochemical Oxygen Demand (BOD) in Groundwater<br>c1. Increase in Respiratory Diseases<br>c2. Generation of $CO_2$ Greenhouse Gas Emissions<br>d1. Decrease in Water Flow<br>e1. Impact of Greenhouse Gases |
| Mushroom Harvesting | Seed Production | For seed production and maintenance of strains, the seed is washed, hydrated, drained, and bagged. This process requires sterilization equipment, pressure cookers or autoclaves, as well as a refrigerator. If the producer prefers to purchase the inoculum from a supplier, the laboratory, the sterile inoculum preparation area, and the incubation room can be omitted [19]. | • Generation of Solid Waste<br>• Generation of Organic Waste<br>• Impact on Groundwater<br>• Water Consumption<br>• Energy Consumption | a. Increase in the amount of solid waste<br>b. Increase in Organic Waste<br>c. Loss of Groundwater Quality<br>d. Increase in Water Consumption<br>e. Increase in Energy Consumption | a1. Loss of Visual Quality of the Landscape<br>a2. Increase in Usable Waste<br>b1. Soil Erosion Generation<br>b2. Impact on Soil Porosity and Structure<br>c1. Impact on Biochemical Oxygen Demand (BOD) in Groundwater<br>d1. Decrease in Water Flow<br>e1. Impact of Greenhouse Gases. |
| | Mycelium Inoculation | Mycelium inoculation involves mixing the mycelium with the substrate. For this, transparent polyethylene bags of 70 x 90 cm are required. The amount of seed is calculated based on the wet weight of the substrate, with a recommended seed quantity ranging from 3.5% to 5% of the wet substrate weight. The bags should be labeled with the inoculation date and placed in the incubation area. This area must be maintained in aseptic conditions and free from air currents. The floor and walls should be easy to clean and preferably white in color [20]. | • Generation of Solid Waste<br>• Generation of Organic Waste<br>• Generation of $CO_2$ Gases<br>• Generation of Particulate Matter<br>• Water Consumption<br>• Energy Consumption | a. Increase in Solid Waste<br>b. Increase in Organic Waste<br>c. Atmospheric Pollution from Gases<br>d. Atmospheric Pollution from Particulate Matter<br>e. Increase in Water Consumption<br>f. Increase in Energy Consumption | a1. Loss of Visual Quality of the Landscape<br>a2. Increase in Reusable Waste<br>b1. Soil Erosion Generation<br>b2. Impact on Soil Porosity and Structure<br>c1. Increase in Respiratory Diseases<br>c2. Generation of $CO_2$ Greenhouse Gas Emissions<br>d1. Increase in Respiratory Diseases<br>e1. Decrease in Water Flow<br>f1. Impact of Greenhouse Gases |

| Phase | ASPI | Description of ASPI | Environmental Aspects | Impacts | |
|---|---|---|---|---|---|
| | | | | Direct Impacts | Indirect Impacts |
| | Bag Dissection | For bag dissection, a perfectly disinfected needle is required to perforate the bags every 5 cm. To proceed with inoculation, the pasteurized straw is dried by allowing steam to escape through turning to remove excess moisture and prevent the growth of organisms that cause substrate rot. The mushroom needs certain porous spaces to allow the exchange of gases, $CO_2$, and oxygen for optimal growth. The optimal temperature for inoculation is between 24 to 25 °C. | • Generation of Solid Waste<br>• Generation of Special Waste<br>• Generation of Organic Waste<br>• Impact on Groundwater<br>• Generation of Gases | a. Increase in Solid Waste<br>b. Increase in Special Waste<br>c. Increase in Organic Waste<br>d. Loss of Groundwater Quality<br>e. Atmospheric Pollution from Gases | a1. Loss of Visual Quality of the Landscape<br>a2. Increase in Reusable Waste<br>b. Impact on Waste Collectors<br>c1. Soil Erosion Generation<br>c2. Impact on Soil Porosity and Structure<br>d1. Impact on Biochemical Oxygen Demand (BOD) in Groundwater<br>e1. Increase in Respiratory Diseases<br>e2. Generation of $CO_2$ Greenhouse Gas Emissions |
| | Incubation | Once the mushroom is inoculated, it begins to grow on the substrate where it was planted. During the first 24 hours, the incubation area should be a dark room equipped with specific structures to hold the bags. This room must maintain a constant temperature required for incubation (18°C) using heaters, as well as energy sources for illumination when necessary. Control of parameters such as temperature, $CO_2$, pH, and humidity is required, so mushroom growth is monitored every three days [21]. | • Generation of Organic Waste<br>• Generation of $CO_2$<br>• Generation of Particulate Matter<br>• Energy Consumption | a. Increase in Organic Waste<br>b. Atmospheric Pollution from Gases<br>c. Atmospheric Pollution from Particulate Matter<br>d. Increase in Energy Consumption | a1. Soil Erosion Generation<br>a2. Impact on Soil Porosity and Structure<br>b1. Increase in Respiratory Diseases<br>b2. Generation of $CO_2$ Greenhouse Gas Emissions<br>c1. Increase in Respiratory Diseases<br>d1. Impact of Greenhouse Gases |
| | Fructification | During the primordia initiation phase, ventilation must be maintained with air injectors and extractors to ensure that fresh air lowers the temperature and removes $CO_2$. The production area is equipped with a sprinkler or misting irrigation system, indirect lighting (50%), 80% humidity, and a temperature range between 18 and 30°C. After 5-6 days from the start of growth, mushrooms can be harvested, taking care not to harvest overly mature | • Generation of Solid Waste<br>• Generation of Organic Waste<br>• Generation of Gases<br>• Generation of Particulate Matter<br>• Water Consumption<br>• Energy Consumption | a. Increase in the Amount of Solid Waste<br>b. Increase in the Amount of Organic Waste<br>c. Atmospheric Pollution from Gases<br>d. Atmospheric Pollution from Particulates<br>e. Increase in Water Consumption<br>f. Increase in Energy Consumption | a1. Loss of Visual Quality of the Landscape<br>a2. Increase in Usable Waste<br>b1. Soil Erosion<br>b2. Impact on Soil Porosity and Structure<br>c1. Increase in Respiratory Diseases<br>c2. Generation of Greenhouse Gas $CO_2$ Emissions<br>d1. Increase in Respiratory Diseases<br>e1. Decrease in Water Flow<br>f1. Impact from Greenhouse Gases |

| Phase | ASPI | Description of ASPI | Environmental Aspects | Impacts | |
|---|---|---|---|---|---|
| | | | | Direct Impacts | Indirect Impacts |
| | | mushrooms that may release spores affecting the personnel [22]. | | | |
| Post-Harvest Activities | Mushroom Harvesting and Storage | Once the mushroom reaches the required size for harvesting (diameter of 7 to 10 cm), it should be cut. The cut must be as clean as possible, using sharp knives. Considerations include: hand hygiene, glove use, disinfection of work surfaces, trays, and buckets. For storage, mushrooms should be kept in a refrigerated environment (0-5°C), well-ventilated, with a $CO_2$ concentration of 0-15%. The storage time should be 1 to 2 weeks, to avoid dehydration of the product [23], [24]. | • Generation of Solid Waste<br>• Generation of Organic Waste<br>• Generation of Gases<br>• Generation of Particulate Matter<br>• Energy Consumption | a. Increase in the Amount of Solid Waste<br>b. Increase in the Amount of Organic Waste<br>c. Atmospheric Pollution by Gases<br>d. Atmospheric Pollution by Particulate Matter<br>e. Increase in Energy Consumption | a1. Loss of Visual Quality of the Landscape<br>a2. Increase in Usable Waste<br>b1. Generation of Soil Erosion<br>b2. Impact on Soil Porosity and Structure<br>c1. Increase in Respiratory Diseases<br>c2. Generation of $CO_2$ Greenhouse Gas Emissions<br>d1. Increase in Respiratory Diseases<br>e1. Impact of Greenhouse Gas Emissions. |
| | Packaging and Packing | The packaging of the caps should be done with the gills facing upwards. Packaging materials such as perforated and non-perforated polystyrene trays can be used. The product should be packed in 50 cm high baskets to prevent excessive weight on the product and transported in vehicles equipped with appropriate refrigeration systems to ensure proper conditions for the product [25]. | • Generation of solid waste<br>• Generation of organic waste<br>• Generation of particulate matter<br>• Generation of noise<br>• Energy consumption | a. Increase in the amount of solid waste<br>b. Increase in the amount of organic waste<br>c. Atmospheric pollution by particulate matter<br>d. Noise pollution<br>e. Increase in the amount of energy consumed | a1. Loss of visual quality of the landscape<br>a2. Increase in Usable Waste<br>b1. Soil erosion<br>b2. Impact on soil porosity and structure<br>c1. Increase in respiratory illnesses<br>d1. Community nuisance<br>e1. Impact on greenhouse gas emissions |
| 0Management Activities | Disposition of Harvest Residues | Once mushroom production is completed, the substrate begins to lose its nutrients and properties, making substrate replacement necessary. This results in organic waste contaminated with spores, which must be properly stored [26]. | • Impact on the visual quality of the landscape<br>• Generation of organic waste<br>• Impact on groundwater<br>• Generation of gases<br>• Generation of particulate matter | a. Loss of visual quality of the landscape<br>b. Increase in organic waste<br>c. Degradation of groundwater quality<br>d. Atmospheric pollution by gases<br>e. Atmospheric pollution by particulate matter | a1. Ecosystem degradation<br>a2. Habitat loss<br>b1. Soil erosion<br>b2. Impact on soil porosity and structure<br>c1. Impact on biochemical oxygen demand (BOD) of water<br>d1. Increase in respiratory illnesses<br>d2. Generation of $CO_2$ emissions, a greenhouse gas<br>e1. Increase in respiratory illnesses. |

| Phase | ASPI | Description of ASPI | Environmental Aspects | Impacts | |
|---|---|---|---|---|---|
| | | | | Direct Impacts | Indirect Impacts |
| | Storage of products, raw materials, and other inputs | The area where materials such as raw materials and additives used for substrate preparation are stored. This area should have shelves for the storage of inputs, with continuous cleaning to control odor, leachate, and pests [27]. | • Generation of solid waste<br>• Generation of organic waste<br>• Impact on groundwater<br>• Generation of odors<br>• Water consumption<br>• Energy consumption | a. Increase in the amount of solid waste<br>b. Increase in the amount of organic waste<br>c. Degradation of groundwater quality<br>d. Increase in offensive odors<br>e. Increase in water consumption<br>f. Increase in energy consumption | a1. Loss of visual quality of the landscape<br>a2. Increase in Usable Waste<br>b1. Soil erosion<br>b2. Impact on soil porosity and structure<br>c1. Impact on biochemical oxygen demand (BOD) of groundwater<br>d1. Community disturbances<br>e1. Decrease in flow rate<br>f1. Impact on greenhouse gas emissions |
| | Mobilization of vehicles, machinery, and | The transportation of materials and finished products will be conducted under a cold chain. This activity generates gas emissions, noise, and fuel consumption. | • Generation of gases<br>• Generation of particulate matter<br>• Generation of noise<br>• Impact on site vegetation cover<br>• Fuel consumption | a. Atmospheric pollution by gases<br>b. Atmospheric pollution by particulate matter<br>c. Noise pollution<br>d. Loss of soil vegetation cover<br>e. Increase in fuel consumption | a1. Increase in respiratory illnesses<br>a2. Generation of $CO_2$ emissions, a greenhouse gas<br>b1. Increase in respiratory illnesses<br>c1. Community disturbances<br>d1. Loss of vegetation formations<br>e1. Atmospheric pollution by gases |
| Administrative management | Hiring of Personnel | Personnel is required for mushroom monitoring, substrate preparation and conditioning, mushroom collection, packing, packaging, and transportation. | • Job creation<br>• Generation of economic income for the community | a. Increase in the number of jobs<br>b. Increase in the amount of economic income for the community | a1. Improvement in the quality of life of the communities<br>b1. Enhancement of the economic dynamics of the community. |
| | Offices | A space is required for overseeing activities and the development of the company, with appropriate lighting conditions, access to technology, and functional spaces needed by the staff. | • Generation of solid waste<br>• Water consumption<br>• Energy consumption | a. Increase in the amount of solid waste<br>b. Increase in water consumption<br>c. Increase in energy consumption | a1. Loss of visual quality of the landscape<br>a2. Increase in Usable Waste<br>b1. Decrease in flow rate<br>c1. Impact on greenhouse gas emissions |

Using the EPM-Arboleda method, the environmental rating of direct and indirect impacts was calculated, and the significance of the environmental impact was established (**Error! Reference source not found.**). After evaluating the impacts, it was found that 1 was very significant, 10 were significant, 9 were moderate, and 18 were minor. This allowed for the calculation of the project's environmental rating, which in this case was 2,13. According to the environmental categorization (Table 3), this is a project with medium impact.

Table 5. Assessment of environmental impacts using the EPM-Arboleda method

| N | Operation | Class (C) | Presence (P) | Duration (D) | Evolution (Ev) | Magnitude (M) | Ca | Impact |
|---|---|---|---|---|---|---|---|---|
| 1 | Loss of visual quality of the landscape | - | 0,7 | 1 | 1 | 0,3 | 3,9 | *M* |
| 2 | Increase in construction waste | - | 1 | 0,2 | 1 | 0,0 | 0,6 | *I* |
| 3 | Atmospheric pollution by gases | - | 1 | 0,4 | 0,4 | 0,5 | 2,6 | *M* |
| 4 | Atmospheric pollution by particulate matter | - | 0,8 | 0,4 | 0,2 | 0,7 | 1,74 | *I* |
| 5 | Noise pollution | - | 0,3 | 0,01 | 1 | 0,18 | 0,38 | *I* |
| 6 | Loss of soil vegetation cover | - | 0,5 | 0,2 | 0,7 | 0,9 | 2,5 | *I* |
| 7 | Increase in fuel consumption | - | 0,3 | 0,4 | 1 | 0,3 | 1,0 | *I* |
| 8 | Increase in water consumption | - | 1 | 0,4 | 0,3 | 0,7 | 2,6 | *M* |
| 9 | Improvement in the visual quality of the landscape | + | 1 | 1 | 0,5 | 1 | 6,5 | *S* |
| 10 | Decrease in organic waste | + | 0,9 | 1 | 0,7 | 0,8 | 6,8 | *S* |
| 11 | Improvement in groundwater quality | + | 0,7 | 1 | 0,3 | 0,4 | 2,6 | *M* |
| 12 | Increase in soil vegetation cover | + | 0,9 | 1 | 0,4 | 0,8 | 5,1 | *S* |
| 13 | Increase in spent substrate | - | 0,8 | 1 | 1 | 1 | 8 | *Vs* |
| 14 | Degradation of groundwater quality | - | 0,5 | 0,4 | 0,0 | 0,3 | 0,61 | *I* |
| 15 | Increase in energy consumption | - | 0,7 | 1 | 0,3 | 0,1 | 2,3 | *I* |
| 16 | Increase in organic waste | - | 0,9 | 1 | 0,5 | 0,7 | 5,3 | *S* |
| 17 | Increase in special waste | - | 0,2 | 0,0 | 0,0 | 0,01 | 0,0 | *I* |
| 18 | Increase in the number of jobs | + | 1 | 1 | 1 | 0,55 | 6,8 | *S* |
| 19 | Increase in economic income for the community | + | 1 | 1 | 0,8 | 0,6 | 6,3 | *S* |
| 20 | Ecosystem degradation | - | 0,2 | 0,2 | 0,3 | 0,2 | 0,2 | *I* |
| 21 | Habitat loss | - | 0,2 | 0,2 | 0,2 | 0,18 | 0,1 | *I* |
| 22 | Increase in soil erosion | - | 0,2 | 0,4 | 0,2 | 0,39 | 0,3 | *I* |
| 23 | Increase in respiratory illnesses | - | 0,4 | 0,9 | 0,2 | 0,4 | 1,3 | *I* |
| 24 | Community disturbances | - | 0,2 | 0,01 | 0,01 | 0,01 | 0,0 | *I* |
| 25 | Soil deterioration | - | 0,4 | 0,2 | 0,01 | 0,2 | 0,2 | *I* |
| 26 | Decrease in flow rate | - | 0,4 | 0,4 | 0,01 | 0,4 | 0,4 | *I* |
| 27 | Improvement in the ecosystem | + | 0,7 | 1 | 0,2 | 1 | 3,0 | *M* |
| 28 | Habitat recovery | + | 0,7 | 1 | 0,3 | 0,77 | 3,2 | *M* |
| 29 | Recovery of soil porosity and structure | + | 0,4 | 1 | 0,55 | 0,9 | 2,5 | *M* |

| N | Operation | Class (C) | Presence (P) | Duration (D) | Evolution (Ev) | Magnitude (M) | Ca | Impact |
|---|---|---|---|---|---|---|---|---|
| 30 | Modification of microbial activity | + | 0,4 | 1 | 0,7 | 0,7 | 2,5 | *M* |
| 31 | Reduction of vectors | + | 0,7 | 1 | 0,4 | 0,5 | 3,0 | *M* |
| 32 | Improvement in groundwater biochemical oxygen demand (BOD) | + | 0,4 | 1 | 0,4 | 0,7 | 1,9 | *I* |
| 33 | Generation of CO2 emissions, a greenhouse gas | - | 0,7 | 1 | 1 | 0,6 | 5,0 | *S* |
| 34 | Improvement in vegetation formations | + | 1 | 1 | 0,7 | 0,8 | 6,9 | *S* |
| 35 | Increase in recyclable waste | + | 0,4 | 0,0 | 0,7 | 0,19 | 0,3 | *I* |
| 36 | Impact on waste collectors | - | 0,2 | 0,0 | 0,0 | 0,0 | 0,0 | *I* |
| 37 | Improvement in the quality of life of the communities | + | 1 | 1 | 0,6 | 0,7 | 5,9 | *S* |
| 38 | Enhancement of the economic dynamics of the community | + | 1 | 1 | 0,6 | 0,7 | 5,9 | *S* |

On the other hand, based on the "Class" criterion, it was found that 15 impacts were positive and 23 were negative (Table 3), having the following:

### 3.1. Positive class impacts

The significant positive environmental impacts resulting from the implementation of an edible mushroom production facility utilizing the CPH by-product are improvements in the visual quality of the landscape, reduction in organic waste, enhancement of groundwater quality, increased vegetation coverage of the soil, and improvement in plant formations. From a socioeconomic perspective, the impacts include an increase in employment, higher economic income for the community, better quality of life for the communities, and an enhancement of the community's economic dynamics.

Moderately, the quality of wastewater improves, the ecosystem is enhanced, habitat recovery occurs, and the porosity and structure of the soil are restored. Additionally, microbial activity is modified, and vectors are reduced.

Among the less significant impacts are the improvement in the biochemical oxygen demand (BOD) of groundwater and the increase in recoverable waste.

### 3.2. Negative class impacts

Significant negative impacts associated with the production of edible mushrooms include an increase in organic waste and the generation of $CO_2$ emissions, a greenhouse gas.

Moderate impacts involve a loss of visual quality of the landscape, atmospheric pollution from gases, and an increase in water consumption.

Less significant impacts identified include increased construction waste, atmospheric pollution from particles, noise pollution, loss of vegetation cover, increased fuel consumption, deterioration of groundwater quality, increased energy consumption, increase in special waste, ecosystem degradation, habitat loss, increased soil erosion, increased respiratory diseases, community nuisance, soil deterioration, decreased water flow, and impacts on waste collectors. It should be noted that some of these impacts are generated during the construction of the production facility, and once operations begin, these impacts are mitigated.

An increase in spent substrate, specifically termed spent mushroom substrate (SMS) for Pleurotus, was established as a very significant impact due to the volume of waste generated. However, studies conducted by [28], [29], [30] on the use of SMS as biofertilizers demonstrate its potential in improving soil health.

According to the document by [17], 160 kg of chopped, wet, pre-pasteurized straw is required to produce an average of 50 kg/day of fresh mushrooms. According to [6] for every ton of dried cocoa beans, 10 tons of cocoa pod husks (CPH) are produced. This means that processing 1 ton of dried beans yields approximately 3,125 kg of mushrooms. Based on the environmental assessment results, the categorization of the increase in organic waste showed a very significant impact due to the spent mushroom substrate (SMS) mentioned by [31]. Therefore, producing 3,125 kg of mushrooms in the first harvest would result in 15,625 kg of SMS.

10000 kg de CPH → 3125 kg of mushrooms →15625 kg SMS

On the other hand, once the components of the by-product CPH are established, a comparison is made between CPH as a substrate for the cultivation of edible mushrooms (**Error! Reference source not found.**).

Table 6. Comparison of the by-product CPH as a substrate for the cultivation of Pleurotus mushrooms

<table>
<tr><th colspan="2">Component</th><th>CPH By-product</th><th>Pleurotus Mushroom</th></tr>
<tr><td colspan="2">% Moisture</td><td>11- 14</td><td>50- 75</td></tr>
<tr><td colspan="2">% Lignin</td><td>14 al 28</td><td rowspan="4">Main Food Source: Lignocellulosic Waste</td></tr>
<tr><td colspan="2">% Cellulose</td><td>19,70 al 44,69</td></tr>
<tr><td colspan="2">% Hemicellulose</td><td>8,70 al 38,08</td></tr>
<tr><td colspan="2">% Pectin</td><td>06 al 12,6</td></tr>
<tr><td rowspan="8">Minerals</td><td>% Phosphorus (P)</td><td>0,10 al 0,19</td><td rowspan="8">Sulfur, phosphorus, potassium, and magnesium ions stimulate the development of Pleurotus. Calcium, zinc, manganese, iron, copper, and molybdenum cations are trace elements that can complement the substrate for these mushrooms.</td></tr>
<tr><td>% Potassium (K)</td><td>2,7 al 3,8</td></tr>
<tr><td>% Calcium (Ca)</td><td>0,25 al 0,6</td></tr>
<tr><td>% Magnesium (Mg)</td><td>0,1 al 0,4</td></tr>
<tr><td>% Iron (Fe)</td><td>0,003 al 0,06</td></tr>
<tr><td>% Manganese (Mn)</td><td>0,036</td></tr>
<tr><td>% Sodium (Na)</td><td>0,01 al 0,02</td></tr>
<tr><td>% Zinc (Zn)</td><td>0,039</td></tr>
<tr><td rowspan="2">C/N ratio of the substrate</td><td>Carbon</td><td>36 a 47</td><td>28 a 30%</td></tr>
<tr><td>Nitrogen</td><td>1,2 a 1,8</td><td>1%</td></tr>
<tr><td colspan="2">pH</td><td>5,5 – 6,25</td><td>6.5 a 7.0</td></tr>
<tr><td colspan="2">Size cm</td><td>10 a 35</td><td>5-6</td></tr>
</table>

The moisture content of CPH on a dry basis is between 11% and 14%. This material can be adjusted and modified by adding water to increase its moisture percentage to meet the requirements of the mushroom. The values of lignin, cellulose, hemicellulose, and pectin obtained from various studies on CPH demonstrate its high lignocellulosic value, which is the primary food source for Pleurotus mushrooms. The mineral content in the cocoa pod husk by-product is mostly below 1%, indicating the need for mineral additives to enhance mushroom development. The pH range of cocoa pod husks is acidic; however, it also requires additives to regulate the pH. Among the substrate adjustments, cocoa husks can be ground to the desired size.

On the other hand, it is recognized that mushroom consumption is increasing globally, with the global market expected to reach 24,05 million tons by 2028 [32]. This includes Agáricus and Pleurotus, which are among the most cultivated in Europe. Additionally, in relation to SMS, 60 million tons of waste were generated in 2018, which is currently used for composting or sent to landfills [31].

## 4. Conclusion

The most relevant aspects of using CPH by-products as a substrate in the production of edible mushrooms were identified from an environmental perspective. This includes identifying significant environmental aspects (ASPI), environmental aspects, and impacts associated with the implementation of a mushroom production facility. Notable aspects include changes in landscape visual quality, the reuse of organic waste, the recovery of areas contaminated by microorganisms and vectors, and the restoration of the physicochemical quality of the soil. Additionally, it was identified that directly, the construction of new structures and the collection of waste affect the visual quality of the area, generate organic waste contaminated by spores or spent substrate, and produce greenhouse gases such as $CO_2$.

From a socioeconomic perspective, it was established that indirectly, there is a high consumption of water, energy, and fuel. However, directly, it will result in monetary income for the community, as well as for the supplier of the substrate and the operator of the edible mushroom production facility.

It was determined that using CPH as a substrate is a cost-effective alternative due to its high volume of waste, which leads to significant mushroom production that can be cultivated easily, with a short growth period and high protein content. Additionally, it generates employment, income, and expectations within the community. Finally, the use of CPH as a substrate for the cultivation of edible mushrooms, evaluated using the EPM method, resulted in a moderate impact rating. This rating was established based on the project's assessment and characterization.

## Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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## Author contributions

Arly Dario Rincón Quintero: Participated in the design and methodology of the study; Wilmar Leonardo Rondón Romero: Supported the formulation of the methodology and data collection; Leidy Mejía CasaDiego: Executed the systematic search for information; Zirley Dayana Ardila Caballero: Established the evaluation of direct and indirect impacts caused by the project; Mauricio Andres Ruiz Ochoa: Performed the analysis and interpretation of the results of the environmental assessment; Luis del Portillo Valdes: supported the development of the draft document. All authors participated in the writing, analysis, and approval of the final manuscript.

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