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TECHNICAL REPORT

Application of hazard analysis and critical control points (HACCP) to the processing of compost used in the cultivation of button mushroom

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Abstract
Purpose Guarantee the product protection and correction of errors, to improve the costs derived from quality defects and to reduce the final over control.
Methods In this paper, the Hazard Analysis and Critical Control Points system is applied to the processing line of compost used in the cultivation of mushrooms and other edible cultivated fungi.
Results From all stages of the process, only the reception of spawn (stage 1), raw materials (stage 3) and composting Phase II—pasteurization and conditioning (stage 7) has been considered as Critical Control Point. The main hazards found were the presence of pathogenic bacteria (stages 1 and 3), the high content in heavy metals (step 3), the use of unauthorized pesticides or doses above the permitted (stage 3), the presence of unauthorized organic matter (stage 3), the contamination by contact with the compost of Phase I (stage 7), and the wrong distribution of compost (stage 7).
Conclusions The implementation of this knowledge will allow the composting plants to control the quality and safety of their products, in order to provide safe compost to the mushroom producing industries.

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Introduction

The basic principle of the White Paper on Food Safety is that food security policies should be based on a comprehensive and integrated scheme, comprising the entire food chain "from farm to table". Thus, control of foods should ensure that they maintain their safety during production, handling, processing, packaging, distribution and preparation, without endangering the health of consumers. The Hazard Analysis and Critical Control Points (HACCP) system was designed to ensure food safety all over the process.

The Hazard Analysis and Critical Control Points (HACCP) is a preventive system which seeks to ensure the security and safety of food, identifies specific hazards associated with food or drinks and establishes control systems that focus on prevention and not on the final product analysis (Leaper 1992; EEC 1993; Ehiri et al. 1995). It is a dynamic system that can cope with new hazard arising from the appearance of emerging pathogens and food poisoning, due to changes in habits and consumption patterns (Pardo et al. 2011).

This system was introduced for the first time in USA, during the National Conference on Food Security in 1971 (APHA 1972). The system has already been implemented successfully in virtually all food sectors, and is expected to be implemented in the primary sector in the next years (EC Regulation 2004), and hence the interest of the present study.

In 2003, the cultivation of mushrooms in the main European producing countries (Netherlands, France and

Spain) began a drastic decline in production, affected by the competition with third countries, especially China, with lower production costs due to the lower cost of manpower and less sanitary control from the local authorities. In this sense, the implementation of HACCP in the different production and processing lines of button mushroom and other cultivated edible fungi (preparation of mycelium and compost, growing and processing cycle for fresh consumption) aims to significantly improve the product quality (Yunsheng et al. 2011), to increase the consumer satisfaction and safety, and to improve the image and competitiveness of mushrooms producing companies.

The main objective of this work is the implementation of HACCP system in the compost elaboration line, which is used in the cultivation of button mushroom and other edible fungi. This will allow the composting companies to design and establish a self-control system to ensure the quality of their productions. In addition, it will facilitate the official control tasks, and will provide a much more complete and objective view of the processes which take place in the composting industries.

Materials and methods

This work is the result of the implementation of HACCP system in the processing line of compost used in the cultivation of button mushrooms and other edible fungi cultivated in different composting plants in La Manchuela (Castilla-La Mancha, Spain). A total of 6 composting plants were visited, selected by the criterion of composting Phase I in bunkers and composting Phase II in traditional pasteurization tunnels. Plants that perform Phase II and III together were not visited. This area produces about 45% of mushrooms grown in Spain. In a first step, information about the process and the physical, chemical and biological raw materials used (spawn, cereal straw, manure, gypsum, supplements) was collected.

An important step in the methodology followed was the development of a flowchart of the entire production process (Fig. 1). Once defined, reviewed and verified that diagram, each of the stages was reviewed in search of potential hazards (physical, chemical or biological) that could be detrimental to food safety (Untermann 1998; Ropkins and Beck 2002).

Once hazards were identified, the preventive measures that could be applied to reduce or annul this hazard were defined. The next step was the determination of the critical control points (CCP) using a tree or sequence of decisions, in which a logic reasoning approach is applied (Cerf and Donnat 2011; Toregeani-Mendes et al. 2011), as recommended by various international organisms (FAO 2001; ICMSF 1991).

When a stage was considered as CCP, the critical limits were defined. Above or below these limits, the process is considered unacceptable. To detect these possible disagreements, a monitoring system was established to make a programmed observation of CCP related to its critical limits. Corrective actions were formulated for each CCP, necessary to correct the possible deviations that may occur.

Finally, a documentation and registration system was established, documenting all HACCP procedures and records that are required to successfully implement the HACCP system.

Results and discussion

The main hazards (physical, chemical or biological) considered in the processing line of compost, as well as the preventive measures to minimize or eliminate the hazard, are shown in Table 1. Those stages considered as CCP based on the application of the decision tree (CAC 1993) are also reflected in the Table 1; with their critical limits, the monitoring system necessary to demonstrate that the CCP is under control, the specific corrective actions and the documentary evidences that may be recorded.

The stages considered as a CCP are: stage 1 (reception of spawn); stage 3 (reception of raw materials); and stage 7 (composting phase II—pasteurization and conditioning). The correct application of the prerequisites (water control plan, cleaning and disinfection plan, manipulators training and control plan, rodent and insects control plan, suppliers control plan, traceability control plan and waste control plan) will prevent or minimize the potential hazards to acceptable levels in the rest of the stages carried out in the processing line of compost (Ropkins and Beck 2003).

The stages considered as a CCP, the potential hazards in these stages, the preventive measures, the critical limits, the monitoring, the actions and the records are described below.

Stage 1—Reception of "spawn"

The spawn is supplied by approved laboratories specialized in the selection and cultivation of mycelium from mushrooms, or provided by companies that multiply the mycelium and manufacture their own spawn.

Usually, a check is performed upon the spawn reception in order to ensure that it arrives in a proper condition with no signs of microbiological contamination or alteration, as their characteristics have a determining influence on the final product quality. A room specifically intended for this purpose must be used, where the appropriate hygienic conditions to prevent possible contamination of the received material are maintained.

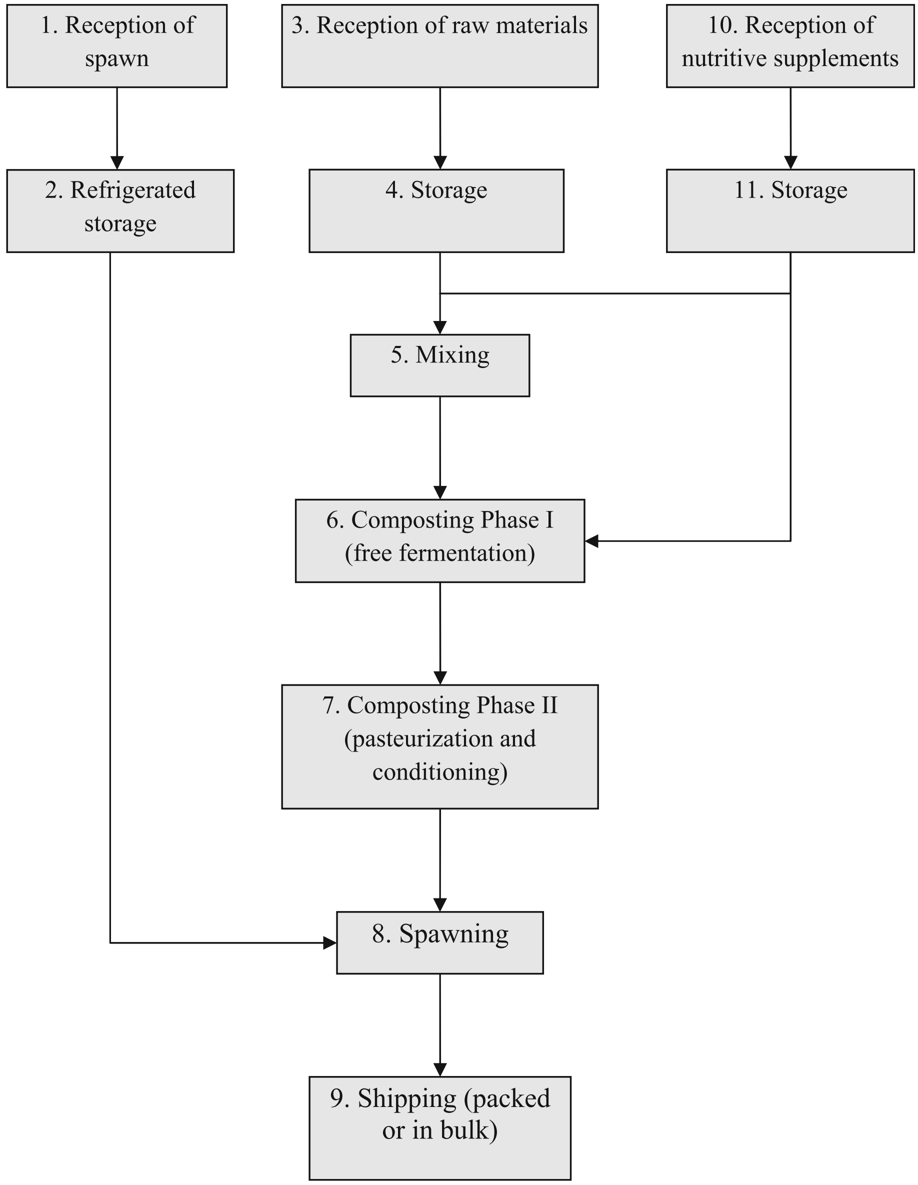

Fig. 1 Flow chart of the elaboration line of compost used in mushroom cultivation

Hazards—One of the main hazards that may appear at this stage is the arrival of a spawn batch with poor quality, with contamination symptoms from pathogen or altering microorganisms. This may be the result of many causes, including the contamination in the spawn preparation line (poor sterilization of cereal grains or contamination during inoculation), or an inadequate transport with frequent blows causing the rupture of the containers and the consequent contamination. Finally, there will be a physical (dirt), chemical or microbiological contamination hazard due to deficient sanitary conditions of the reception facilities.

Preventive measures—In order to minimize possible hazards, it is essential the approval of suppliers. Prior to approval, suppliers must be visited to check that they fulfill the hygienic and quality standards required. In addition, each batch received must be visually checked to guarantee the integrity of the product and the hermetic nature of the plastic bags that cover the spawn, in order to maintain the proper aseptic conditions. To avoid any damage to the plastic bags, the transport should be done in carton boxes.

The reception of the spawn must be performed in facilities with adequate sanitary conditions, where the cleaning and disinfection plan must be applied to guarantee the perfect conditions of the spawn until the moment of inoculation. The transport to its storage location must be as fast and careful as possible.

Critical limit—The critical limit will be fixed according to the requirements set by the company in terms of microbiological specifications of the spawn for the

Table 1 Synoptic of application of the elaboration line of compost used in the cultivation of mushroom and other edible fungi

Stage	Type of hazard			Hazard	Preventive measures	CCP	Critical limits	Monitoring	Corrective actions	Records
	Physical	Chemical	Biological							
1. Reception of spawn	X	X	X X	Batch with a poor microbiological quality Bad hygienic and sanitary conditions in the reception room	Approval of suppliers Visual observation of the batches received Application of the C + D plan in the reception facilities Quick and careful transportation	Yes	Compliance of the established specifications Spawn containers without breaks or other damages	Visual inspection of each batch Inspection of the containers and the transportation conditions Analytical control of random samples	Reject the batches that do not meet the established specifications Remove the approval of suppliers	List of approved suppliers Purchase specifications Reception delivery notes Analyses performed Incidents and corrective measures applied
2. Refrigerated storage of the spawn	X	X	X X	Bad hygienic and sanitary conditions in the storage facilities Proliferation of microorganisms	Application of the C + D plan in the facilities Preventive maintenance of the refrigeration system Proper placement of the load and rotation of the stocks	No				
3. Reception of raw materials		X X X	X X	High content of heavy metals High presence of pathogens Presence of phytosanitary residues Presence of organic raw materials	Approval of suppliers Demanding quality certificate Request certificate of no urban waste origin, and absence of blood or meat meal Analytical control	Yes	Compliance with the Royal Decree 824/205 on fertilisers/ Compost	Certificate of origin and composition of the raw materials Microbiological and heavy metals analysis	Reject the batches that do not meet the established specifications Remove the approval of suppliers	Reception delivery notes Purchase specifications Analyses performed Incidents and corrective measures applied
4. Storage of raw materials		X	X X	Contamination by inadequate water quality Presence of excessive levels of pathogen parasites	Ensure the adequate water quality Treatment with authorized insecticides	No				

Table 1 continued

Stage	Type of hazard			Hazard	Preventive measures	CCP	Critical limits	Monitoring	Corrective actions	Records
	Physical	Chemical	Biological							
5. Mixing		X X	X	Contamination by inadequate water quality Inadequate structure and high pH of the mixture	Ensure the adequate water quality Supervision of the mixing process Analysis of the mixture composition Addition of structure and pH enhancers	No				
6. Composting Phase I (free fermentation)		X X	X X X X	Diseases from the contact surfaces Growth of pathogen parasites in the tunnel Inadequate turning Contamination by inadequate water quality	Application of the C + D plan in the facilities and equipment Composting in a cemented and covered area Ensure the adequate water quality Maintenance of the oxygenation equipment Check the instruments Control of temperature and duration of the stage	No				
7. Composting Phase II (pasteurization and conditioning)	X	X	X X X X X	Contamination by contact with the compost from Phase I Bad hygienic and sanitary conditions in the facilities Malfunction of equipment Inadequate operators training Bad compost distribution	Pasteurization tunnel with two doors Application of the C + D plan in the facilities Proper empting and maintenance of the tunnel Operators training Exhaustive control of parameters (temperature, O_2, etc.) Compost leveling Periodic analysis of compost after Phase II (Recommended values of moisture −60 to 75%, C/N ratio −16 to 22/1, pH −7 to 9 and total N −1.7 to 2.6%)	Yes	Adequate construction of the tunnel T°/initial time: 48 °C, 1–2 days T°/third day time: 60 °C, 6–8 h T°/final time: 48 °C, 4–6 days Adequate level of the compost	Visual inspection of the composting plant Periodic inspection of temperature and duration of the phases Analytical control of compost random samples Leveling of the compost	Correct constructive conditions Temperature and time control Remove suppliers approval Reject inadequate batches Repeat pasteurization process	Composting plant drawings Data from the filling, quantities, moisture, temperature, leveling, etc Analyses performed Incidents and corrective measures applied

Table 1 continued

Stage	Type of hazard			Hazard	Preventive measures	CCP	Critical limits	Monitoring	Corrective actions	Records
	Physical	Chemical	Biological							
8. Spwaning		X	X X X	Microbiological contamination due to lack of hygiene in facilities, equipment and operators Contamination by chemical residues from cleaning products Infection by bacteria causing mummification	Application of the C + D plan in the facilities Good hygiene and manipulation practices of operators Analysis of the compost Revision of spawn quality	No				
9. Shipping (packed or in bulk)		X	X	Contamination by bad hygiene and sanitary conditions of the pressing plates and packing materials	Application of the C + D plan in the facilities Prohibit the transportation of compost in vehicles that have transported used compost	No				
10. Reception of nutritive supplements	X	X X	X X	Reduction or loss of action power of the active substance Bad hygienic and sanitary conditions in the reception room	Approval of suppliers Visual inspection of the batches Application of the C + D plan in the reception facilities	No				
11. Storage of the nutritive supplements		X X	X X	Alteration of the products Contamination from the associated facilities	Comply with manufacturer's instructions Facilities sheltered from the outside environment Application of the C + D plan in the facilities Storage separated from transit zones	No				

approval of suppliers. If there were fungal or bacterial contaminations (*Thrichoderma* sp., *Neurospora* sp., *Penicillium* sp., *Aspergillus* sp. and others) in the spawn, it would be rejected. The containers used must be undamaged, without any break that could originate microbial contamination of the spawn.
Monitoring—The person in charge should perform a visual inspection of each batch upon arrival to the company to check that all defined specifications are met. In addition, the transport conditions and the physical state of boxes and plastic bags must be inspected. Analytical controls must be done taking two random samples from each batch.
Corrective actions—All the batches that do not meet the company requirements will be rejected. In addition, those batches that arrive in a poor physical condition or do not pass the analytical control will also be rejected. When a supplier shows a negative recurring behavior, the approval may be removed.
Records—A list of approved suppliers will be created, including the purchase specifications that the product must meet. A record sheet will be created to register every batch entry, the date of arrival, the results of the visual inspections, the analytical controls performed and the rejected batches. The incidents that occurred during this stage and the corrective measures applied will also be recorded.

Stage 3—Reception of raw materials

The main constituent of the synthetic compost is cereal straw. This element is transported in compacted bales tied with ropes on trucks. The straw, which is the main carbon source, is responsible for the compost texture, allows natural ventilation and its organic matter determines the water retention capacity. The wheat straw is preferably used due to its firmness, texture conservation and availability, although other straws are also used such as rye or barley.

Afterwards, the straw is mixed with other raw materials and after fermentation and pasteurization gives rise to a compost whose structure and composition allows proper and healthy development of mushrooms. The rest of raw materials received are:

- Chicken manure. Mixed with sawdust and wood shavings from the chicken bed, the chicken manure is the most important nitrogenous ingredient in the compost elaboration. This material is usually pretty dry, can be stored and its supply is easy and stable. The manure from laying hens in batteries has a similar composition, but its distribution and mixture are more difficult because it is a wet and oily material.
- Other nitrogenous additives. Materials such as urea and ammonium sulfate are commonly used as supplements to the nitrogen provided by the chicken manure.
- Gypsum. The gypsum or calcium sulfate ($CaSO_4 \cdot 2H_2O$) is important for a stable production of compost. The gypsum contributes to a lowering of pH and improves the compost texture, as it flocculates the colloidal particles that originate the oily look of the compost. It seems to have a great influence, especially when chicken manure is used in large quantities. It is also used as a calcium source for the mushroom and enables the transformation of oxalic acid secreted by the mycelium in calcium oxalate.
- Water. It is necessary a continuous hydration of the mixture.

Hazards—At this stage, the main hazard lies in the chemical composition (high presence of heavy metals) and microbiological (high content of pathogenic microorganisms) of the raw materials. In addition, the presence of phytosanitary residues and the input of organic raw materials as a vehicle for viruses or diseases should also be considered.
Preventive measures—When the raw materials selection is done with the maximum quality requirements, there is a lower probability of appearance of pathogens or chemical problems. First, it is necessary to approve the suppliers of raw materials, with the definition of the purchase specifications and demanding a quality certification. This certification will ensure the compliance of the maximum requirements demanded for raw materials with regard to phytosanitary residues and pathogen levels, and allows to ensure that hazards will be reduced to acceptable levels in subsequent stages. On the other hand, it is necessary to certify that organic matter does not come from urban waste, which is a great problem due to the possible appearance of high levels of heavy metals. They are not degraded in later stages and could be assimilated by the mushroom, which will result in a hazard to the health of consumers. The entry of raw materials with dried blood or meat meal will not be permitted due to the possible transmission of viruses and diseases to the final product. Two random samples must be analyzed from each raw materials batch to determine the level of microbiological and chemical contamination and to ensure that the raw materials are within the authorized limits and guaranteed by suppliers.
Critical limit—The compost should meet the current limits established in the law (Spanish Royal Decree 824/2005, from July 8, on fertilizer products—https://www.boe.es/boe/dias/2005/07/19/pdfs/A25592-25669.pdf), which is quite restrictive in terms of permitted ingredients and maximum levels of heavy metals, to preserve food security and environment.
Monitoring—A certificate of the origin and composition of raw materials will be demanded to suppliers. The

composting plant must arrange a random sampling plan to control the quality of the batches received, where a careful control of heavy metals and pathogens must be done. The quality committee will be responsible to analyze two random samples from each batch, based on predefined parameters.

Corrective actions—Batches of raw materials that exceed the limits allowed for heavy metals or pathogens will be rejected. If the problem persists with the same supplier, the approval will be removed, and another supplier will be selected.

Records—The entry of raw materials, its origin, the identification of suppliers and the required specifications will be registered. An exhaustive control in the results obtained from the analysis performed to the raw materials must be done, especially in the content of heavy metals and pathogens. The incidences observed in the reception of raw materials and the corrective measures applied must be registered.

Stage 7—Composting Phase II (pasteurization and conditioning)

This stage of composting process consists in a directed and controlled fermentation. The compost is introduced in totally isolated tunnels where the adequate conditions of temperature, humidity and oxygenation are achieved to get the perfect finish of the compost. Instruments such as long distance thermometers, fans, steam injection systems, valves and boilers are used to facilitate the control at this stage.

The pasteurization tunnel is a rectangular room, generally with a width of 3–4 m, with insulated walls and roof, a false floor with slits and a slope of 2% for runoff when it is cleaned, and where air and steam are injected to maintain the controlled temperatures of compost. The tunnel is filled with compost from Phase I and it is constantly ventilated to increase the temperature. If temperature does not rise, steam is injected from a boiler. The ducts transporting steam, fresh air and recycled air, must be covered by an insulated material to prevent heat loss, and the systems that introduce air from outside must be provided with anti-spore filters.

The height from the floor to the ceiling is about 3.5–4 m, ensuring that the work of filling will not be limited when endless belt or tractors are used. Usually, the tunnel is filled to a height of 1.8–2 m. If this height is exceeded, an effect of anaerobiosis by compaction of compost can be provoked. On the other hand, when this height is lower than 1.6 m, the tunnel probably does not reach the temperature values required and the injection of steam is necessary.

The objective of this stage is the development of a specific microbial flora, particularly of *Actinomycetes*. A selective final product is obtained for the subsequent development of mycelium from *Agaricus bisporus* (Lange) Imbach, while volatile ammonia, toxic for the mycelium is removed. The development of pests and diseases is destroyed or limited (Pardo 1999). During this process, there are three important moments:

- Colonization: The temperature is maintained between 48 and 55 °C for 1–2 days with the purpose of the reproduction of bacteria and other mesophilic organisms to continue the process of cleavage of lignin, cellulose and nutrients contained in the compost.
- Selection of microorganisms or pasteurization: the temperature is gradually increased to 60 °C and is maintained for 6–8 h to eliminate undesirable organisms such as insects, nematodes, spores from other fungi, larvae, spiders, mites, etc.
- Reproduction of microorganisms or re-colonization, also called conditioning: the temperature is gradually decreased to 48 °C over 4–6 days. The objective is to finish the biological processes and increase the selectivity, favouring the development of actinomycetes and thermophilic fungi.

The overall duration of the stage is 6–8 days, providing the necessary conditions to ensure the aerobic conditions of the process.

Hazards—First, a biological hazard can be found, as the compost that has finished this stage and is ready to be spawned may be contaminated by contact with the compost from Phase I, which is ready to begin the pasteurization process. Another major hazard is the neglect of sanitary conditions in the facilities, which leads to conditions that favor the microbiology contamination, the occurrence of diseases and the appearance of pathogens that may be harmful for the finishing of compost and the subsequent growth of mushrooms. When the equipment responsible for keeping the temperature and oxygenation conditions does not work properly, which is not adequately controlled or calibrated, the main objective of the pasteurization process is impeded. Thus, certain organisms detrimental to the growth of the mushrooms may be developed with the subsequent consequences in the mushroom growth. In addition, an insufficient training of the personnel responsible for controlling the monitoring system may also lead to a hazard for the correct conduct of this stage. However, it is sufficient to establish preventive measures to eliminate or reduce this hazard to acceptable levels. When the tunnel is being filled, if the compost is unevenly distributed, the irregularities of the compost may serve as a refuge for some pests and diseases since the pressure of the air injected into these areas will be lower than the rest.

Preventive measures—According to hygiene reasons and the perfect operational flow, the pasteurization tunnel must have two doors: one of them to fill the tunnel with the compost from Phase I, commonly located nearby the composting yard, and the other door on the opposite side of the tunnel, through where the finished compost is evacuated to the spawning area, which is considered clean area. This flowchart will avoid wasting time in the work of filling of the tunnel and spawning, and will restrain the appearance of possible diseases originated by the contamination due to the contact of the pasteurized compost with the dirty or composting areas.

Another preventive measure to be considered is the application of a cleaning and disinfection plan of the facilities, with authorized chemical products. Within this plan, it is recommended the abolition of all compost generating activities during a minimum period of 30 days and the realization of a sanitary break. Furthermore, the maintenance and conservation of the tunnels with a treatment of walls and roof with asphalt paint or other similar authorized material should be done at least once a year.

These measures aim to avoid many parasitic and microbiological contamination hazards, and to avoid the chemical hazard from residues of cleaning products. It will be essential: (1) A preventive maintenance program of the equipment from the oxygenation, steam injection and temperature control systems, (2) periodic reviews to ensure the good state of thermometers, steam injection tubes, valves and boiler, (3) disinfection, or even changing the filters in air inlets and outlets, and (4) installation of anti-spore filters on the air inlets, which also prevent the entry of insects.

The necessary training will be given to the workers before the beginning in the workplace, and periodic inspections will be done on subsequent years to ensure the proper application of guidelines and procedures. A designated worker will perform a thorough check of the parameters involved in this stage (temperature, oxygen, air flow, pressure and duration of phases), using the computerized system that registers the records.

It is important a proper leveled of the compost at the time of filling the tunnel, so that there are no irregularities on the surface which may serve as a refuge for pests and diseases. Conducting periodic analyses of the compost composition checking nitrogen, organic matter, ashes, C/N ratio, moisture, ammonia (throughout the process), pests and diseases, chemical residues and presence of heavy metals will allow to detect on time any mishap that may affect the safety of mushroom cultivation.

Critical limit—The pasteurization tunnels must meet certain constructive conditions regarding dimensions and isolations of ceiling and walls, a false floor with a grid and a slope of 2% (with a minimum recommended distance between the real and the false floor of 90 cm, where the steam and air injection conducts are connected), and two different doors, one connected to the clean area (spawning) and the other one (filling) connected to the dirty area or the yard of Phase I composting. It is necessary the correct control of the temperatures for each moment:

- Starting temperature for the homogenization or colonization of 48 °C for 1–2 days.
- From the third day, the temperature is raised and maintained at 60 °C for 6–8 h (pasteurization).
- This stage ends at 48 °C during the following 4–6 days to complete the conditioning of compost.

A good leveled of the compost and its distribution as evenly as possible throughout the pasteurization tunnel must be achieved.

Monitoring—An inspection of the constructive characteristics of the composting plant will be made, with special attention to the pasteurization tunnel design and the composition of the materials that are used for its construction. In addition, it is essential to perform periodic inspections of temperature and duration of the phases, which ensure the proper development of the whole process. The compost composition must also be analyzed periodically, with special attention to the appearance of chemical residues and the possible detection of undesirable pests and diseases.

Corrective actions—The constructive deficiencies must be corrected, as well as the ones that occur due to the obsolescence of the equipment and facilities. When the records of temperature, steam injection, oxygenation, and the length of the different phases are not the established, they must be adjusted and the tuning of the equipment that measure these parameters must be performed.

When the compost composition analyses show levels that exceed the established limits for chemical residues or heavy metals, the compost batch must be rejected due to the risk for the health of consumers of mushrooms produced with this compost. However, if the analyses show signs of disease or pests that may be eliminated or reduced to acceptable levels by the process of pasteurization, the process on this batch must be repeated.

Records—A drawing of the structure design of the facilities will be required. In addition, the materials and the characteristics of the composting plant must be added, in particular the pasteurization tunnels. Records sheets must be complimented with the data regarding the filling date, humidity and nitrogen percentage, the quantity of compost introduced in the tunnel, and the hourly records of temperatures, steam injection, percentage of fresh air (considered as the air injected from outside), and percentage of air recirculation inside the tunnel and other observations.

In addition, the recording of the periodic analyses performed over the whole process is essential, because it indicates the correct evolution of the compost. Furthermore, the incidences arising at this stage and the corrective measures applied must also be registered.

Conclusions

The implementation of this procedure will allow the composting plants to control the quality and safety of their products, to provide safe compost to the mushroom producing industries.

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Author contribution Each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content.

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