Application of Hazard Analysis and Critical Control Points (HACCP) to the Cultivation Line of Mushroom and Other Cultivated Edible Fungi

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Abstract The Hazard analysis and critical control points (HACCP) is a preventive system which seeks to ensure food safety and security. It allows product protection and correction of errors, improves the costs derived from quality defects and reduces the final overcontrol. In this paper, the system is applied to the line of cultivation of mushrooms and other edible cultivated fungi. From all stages of the process, only the reception of covering materials (stage 1) and compost (stage 3), the pre-fruited and induction (step 6) and the harvest (stage 7) have been considered as critical control point (CCP). The main hazards found were the presence of unauthorized phytosanitary products or above the permitted dose (stages 6 and 7), and

the presence of pathogenic bacteria (stages 1 and 3) and/or heavy metals (stage 3). The implementation of this knowledge will allow the self-control of their productions based on the system HACCP to any plant dedicated to mushroom or other edible fungi cultivation.

Keywords Cultivated mushroom · Hygiene · Quality · Security · Self-control

Introduction

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 establish control systems that focus on prevention and not on the final product analysis [1–3]. It is a dynamic system that can cope with new dangers arising from the appearance of emerging pathogens and food poisoning, due to changes in habits and consumption patterns [4].

Apart of improving food safety, the application of the HACCP system can provide other significant benefits such as the ease of inspection by regulatory authorities, the reduction of final product losses (reducing the causes of product alteration) and the promotion of international trade by increasing the confidence in food safety. All of sanitary supranational institutions consider this system in their programs, recommending its use, not only for industry, but throughout the food chain, from the primary producer to the final consumer.

In 2003, the cultivation of mushrooms in the main European producing countries (Netherlands, France and Spain) began a drastic decline in production. The main reason of this decline in production is the fierce competition with third countries, especially China, with lower costs production due to the lower cost of manpower and less

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Fig. 1 Flow chart of the mushroom cultivation line

sanitary control from the local authorities. In this sense, the implementation of HACCP in the different production and processing lines of mushroom and other cultivated edible fungi aims to significantly improve the product quality [5], 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 cultivation line of mushroom and other cultivated edible fungi. This will allow the growing 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, providing a much more complete and objective vision of the processes in the cultivation line of mushrooms.

Materials and Methods

In order to establish the HACCP system in the cultivation lines of mushroom and other edible fungi, different cultivation plants located in the area of Manchuela (Castilla-La Mancha, Spain) were visited. This region produces 45 % of mushroom total production in Spain. The first step consisted in the collection of information related to the process

and the physical, chemical and biological properties of the raw materials used (previously inoculated compost and substrate coverage).

An important step in the methodology to establish the HACCP system is the development of a flow chart of the entire production process (Fig. 1). Once defined, reviewed and verified this diagram, a revision of the process is done in order to determine potential physical, chemical or biological hazards that could be detrimental to food safety [6, 7].

A set of preventive measures are defined to be applied in order to reduce or nullify the hazards identified in the previous step. After that, the critical control points (CCP) are determined using a tree or sequence of decisions [8, 9], which indicates a logic reasoning approach, as recommended by various international organizations [10, 11].

Critical limits are defined for each stage considered as CCP. Above or below these limits, the process is considered unacceptable in order to ensure food safety. A monitoring system is established in order to enable to detect the potential alterations and to measure or schedule observations of the CCP according to its critical limits.

Subsequently, the corrective measures specific to each CCP are formulated to deal with deviations when they occur.

Finally, a system of documentation and recording is established to document all procedures of the HACCP

system and all records that were necessary to carry out the correct implementation of the HACCP system.

Results and Discussion

Table 1 summarizes the main hazards that may be found for each stage of the mushroom cultivation process. The type of hazard (physical, chemical or biological) is indicated, as well as the preventive measures to be considered to minimize or eliminate the hazard. The stages that are considered CCP after applying the decision tree are also indicated, with their critical limits, the monitoring necessary to demonstrate that the CCP is under control, the specific corrective actions, and the documentary evidences to be recorded [12].

Only stages 1 (receipt of casing materials), 3 (fill-receipt of compost), 6 (pre fruiting-induction), and 7 (harvest) can be considered as CCP in the process. In the rest of stages, the correct application of the prerequisites of the HACCP system [13] (water control plan, cleaning and disinfection plan, training plan and control of manipulators, maintenance plan, insect and rodent control plan, suppliers control plan, traceability control plan, and waste control plan) will prevent or minimize the potential hazards to acceptable levels. The hazards, preventive measures, critical limits, monitoring, corrective measures and the records associated to each stage considered as CCP are described below.

Stage 1: Reception of Casing Materials

The casing layer provides an optimal medium for mushroom fruiting due to its characteristics of porosity, water retention, pH, etc. [14]. Currently, in the region of Manchuela the casing layers are based on the use of mineral soil from different origins (topsoil, subsoil, etc.), with the addition of other materials to correct the structure and water retention such as sphagnum peat that must be imported, or black peat from national origin [15].

The casing materials are subjected to controls in the reception to ensure that they arrive in perfect conditions and without signs of microbial contamination or alteration, as their characteristics have a determining influence on productivity and quality of the final product. A room intended specifically for this purpose is available at the mushroom industries, where appropriate hygienic conditions are kept to prevent microbial contamination or alteration.

Hazards

The main hazard of this stage is the presence of pathogenic microorganisms in the casing material [16]. These

microorganisms may remain in the ground along the whole crop cycle, contaminating the mushroom before harvesting and therefore, they can be ingested by the consumer. The other hazards of this stage will be eliminated or minimized to acceptable levels after the proper application of the plans included in the prerequisites of the HACCP system.

Preventive measures: The analysis of the casing material at the reception will be essential. The reception must be done at a location with good sanitary conditions. With this purpose, an adequate cleaning and disinfection program must be applied.

Critical limit

The critical limit will be established according to the type of pathogenic microorganism present in the casing material.

Monitoring

The casing material will be analyzed from the microbiological point of view before the beginning of the cultivation cycle.

Corrective measures

When high levels of pathogenic microorganisms are detected, the casing material should be discarded and substituted by other with higher microbiological quality.

Records

The analysis done to the casing material will be registered. In addition, the incidences occurred during this stage and the corrective measures applied will be annotated.

Stage 3: Fill-Receipt of Compost

At this stage, the previously inoculated compost bags are placed on the shelves of the cultivation plant, separated by corridors of sufficient width to allow the realization of the cultivation works. In addition, the cultivation plants must have a series of mandatory aspects: they must be isolated from the outside environment; with a paved floor, polished and with slope to drain the wash water; with heating and ventilation systems, etc. Other recommended aspects include the automatic climate control.

Hazards

In a similar way as mentioned with casing materials, the main hazard of this stage consists in the use of compost contaminated with pathogenic microorganisms [17]. The contamination may originate from the inadequate production processes

Table 1 Synoptic of application of the mushroom cultivation line

Stage	Type of hazard		Hazards	Preventive measures	CCP	Critical limit	Monitoring/ frequency	Corrective measures	Records
	Physical	Chemical	Biological						
1. Reception of casing materials			X	Presence of pathogenic microorganisms in the casing materials	Yes	According to the type of pathogenic microorganism	Microbiological analysis of the casing materials	Replacement of casing	Analysis done
		X	X	Poor hygienic and sanitary conditions of the reception room					Incidences and corrective measures
2. Storage of casing materials	X	X	X	Dirtyness (insects, dust, etc.)	No	Application of the cleaning and disinfection plan			
			X	Contamination with parasites and pathogenic microorganisms					
3. Filling (reception of compost)			X	Presence of pathogenic microorganisms in the compost	Yes	According to the type of pathogenic microorganism and heavy metals	Microbiological and chemical analysis of the compost	Replacement of the compost	Analysis done
	X			High levels of heavy metals in some ingredients of the compost					Incidences and corrective measures
	X	X	X	Poor hygienic conditions of the installations and transport				Quick and careful transport	
				Avoid overlapping of filling and emptying in plants closer than 150 m					
			X	Contamination with the removed compost from nearby plants				Temperature, humidity and air control	
			X	Appearance of pests				Installation of insect traps	
4. Germination/Incubation	X	X	X	Appearance of pests and diseases	No	Application of the cleaning and disinfection plan			
			X	Contamination by the inadequate quality of irrigation water		Preventive maintenance of refrigeration system			

Table 1 continued

Stage	Type of hazard		Hazards	Preventive measures	CCP	Critical limit	Monitoring/ frequency	Corrective measures	Records
	Physical	Chemical	Biological						
5. Casing				Control of air, environment and substrate temperature, humidity, CO ₂ and aeration					
				Installation of mosquitoes traps					
				Application of insecticide treatments					
				Ensure the quality of irrigation water					
			X	Poor hygienic and sanitary conditions		No			
			X	Contamination due to lack of hygiene in the casing tools					
		X		Contamination with chemical residues from the tools cleaning					
			X	Appearance of pests and diseases					
			X	Contamination with nematodes, bacteria and fungi from casing layer					
	X	X		Contamination by the inadequate quality of irrigation water					
6. Pre fruiting/ Induction		X		Use of unauthorized phytosanitary products, or in higher doses than allowed or without respecting the security period	Yes	Use of authorized phytosanitary products, in adequate doses and respecting the security period	Phytosanitary products, doses and security periods	Correction of treatments program	Phytosanitary application (products, doses, security period, active ingredients, etc.)

Table 1 continued

Stage	Type of hazard		Hazards	Preventive measures	CCP	Critical limit	Monitoring/ frequency	Corrective measures	Records
	Physical	Chemical	Biological						
	X		X	Poor hygienic conditions inside the plant		Application of cleaning and disinfection plan		Replacement of phytosanitary products	Incidences and corrective measures
			X	Lack of hygiene in the personnel		Minimize the transit of personnel inside the cultivation plant, and disinfection of the footwear at the entrance		Destruction of the crop when it exceeds the phytosanitary residues allowed for mushroom	
			X	Appearance of pests and diseases		Installation of mosquitoes traps			
	X	X	X	Contamination by the inadequate quality of irrigation water		Ensure the adequate environment conditions inside the plant Application of granulated chlorine to avoid staining of mushrooms at the beginning of each flush Stop the production at the third flush Ensure the quality of irrigation water			
7. Harvesting	X			Use of unauthorized phytosanitary products, or in higher doses than allowed or without respecting the security period	Yes	Application of authorized phytosanitary products, in adequate doses and respecting the security period	Phytosanitary products, doses and security periods	Correction of treatments program	Phytosanitary application (products, doses, security period, active ingredients, etc.)
			X	Microbiological contamination due to lack of hygiene of manipulators		Application of good hygiene and food manipulation practices		Replacement of phytosanitary products	

Table 1 continued

Stage	Type of hazard		Hazards	Preventive measures	CCP	Critical limit	Monitoring/ frequency	Corrective measures	Records
	Physical	Chemical	Biological						
			X	Microbiological contamination by poor hygienic and sanitary conditions inside the plant	Minimize the transit of personnel inside the cultivation plant				
					Application of cleaning and disinfection plan				
		X	X	Microbiological and chemical contamination due to lack of hygiene or presence of residues of cleaning products in the harvesting containers	Installation of mosquitoes traps				
8. Dispatching					Post harvesting cleaning				
					After each flush				
				Contamination by consecutive flushes	Use of clean containers or disinfected in case they are reused				
9. Emptying			X	Microbiological contamination of the product	Application of cleaning and disinfection plan	No			
					Application of good hygiene and food manipulation practices				
					Quick, careful and refrigerated transport				
	X		X	Contamination from other buildings	Previous treatment of non empty installations with steam	No			
					Avoid the transit by nearby buildings				
					Immediate removing after the harvesting of the last flush				
								Destruction of the crop when it exceeds the phytosanitary residues allowed for mushroom	Incidences and corrective measures

Table 1 continued

Stage	Type of hazard		Hazards		Preventive measures	CCP	Critical limit	Monitoring/ frequency	Corrective measures	Records
	Physical	Chemical	Chemical	Biological						
10. Cleaning and disinfection	X	X	X	X	Unadequate cleaning of the installations and use of non recommended products (permanence of chemical residues)	No	Application of an adequate cleaning and disinfection plan			
					Approval of suppliers		Prohibition of unauthorized products			
11. Authorized compost manager	X	X	X	X	Contamination of nearby installations	No	Cubrir con una lona durante su transporte			
					Separated and distant location of cultivation and food manipulation premises		Easy access for loading and unloading			
					Periodic review to prevent leakage or deterioration of containers					
12. Reception of auxiliary material (phyto-sanitary products, containers, supplements, etc.)		X	X	X	Poor hygienic and sanitary conditions of reception installations	No	Application of cleaning and disinfection plan			
			X	X	Contaminated containers and/or additives		Approval of suppliers (demand characteristics and specifications)			
	X				Containers breakage and possible leakage of chemicals					
13. Storage of auxiliary material	X	X	X	X	Poor hygienic and sanitary conditions of installations	No	Application of cleaning and disinfection plan			
					Fulfill the manufacturer's indications					

Table 1 continued

Stage	Type of hazard		Hazards	Preventive measures	CCP	Critical limit	Monitoring/ frequency	Corrective measures	Records
	Physical	Chemical Biological							
				Installations protected from the external environment Adequate stacking					
X indicates whether the hazard found at each stage is physical, chemical or biological									

of compost or it may be produced in the cultivation plant when the compost arrives or by direct contact with the compost that is being removed from a nearby plant. In addition, the compost can be contaminated due to the movement of personnel without the proper hygienic conditions in hands, clothes or footwear, or due to the opening of the cultivation plant for too long periods. The correct application of the prerequisites prevents contamination of compost in the cultivation plant or through the personnel, but will not prevent the previous contamination of the compost, before entering into the cultivation plant. A chemical hazard to consider consists of the possible presence of high levels of heavy metals (cadmium, lead, copper, etc.) in the compost. The heavy metals may be present in some of the ingredients used to prepare the compost, like straw, manure, etc.

Preventive measures

The compost must be analyzed in the reception to detect the presence of pathogens and heavy metals. To ensure the optimal hygienic conditions at the beginning of the cultivation, the plant must be subjected to a complete sweeping, washing and disinfection prior to the filling. In addition, the strict hygienic conditions must be maintained throughout the cultivation cycle. The filling of the shelves must be done with care and in the shortest time possible, ensuring that the compost bags do not suffer breakage. It must be avoided to fill the cultivation plant coinciding with the emptying of a crop done to less than 150 m away. This way, the contamination of the newly inoculated compost with the removed one is prevented. The contamination levels will decrease significantly when the personnel that is in direct contact with the material in process is concerned about keeping their conditions of cleanliness. The use of clean clothes and footwear will be a preventive measure. The installation of insect traps will prevent the occurrence of pests and will help in their detection. The adequate control of air and compost temperature, humidity and CO₂ is essential immediately after the filling of the cultivation plant.

Critical limit

The critical limit will be established according to the type of pathogenic microorganism and the heavy metal present in the compost. The recording of the operations of filling and emptying will establish the synchronization of these operations to avoid the overlap in nearby plants.

Monitoring

The compost will be analyzed from the microbiological and chemical points of view before the beginning of the

cultivation cycle. On the other hand, the filling and emptying of nearby plants will be considered to avoid the overlap of these operations.

Corrective measures

When high levels of pathogenic microorganisms or heavy metals are detected, the compost will be discarded and substituted by other with higher microbiological and chemical quality. The traceability of the substrates quality from the supplier companies of compost and their internal controls can be useful tools to consider. When an overlap of the operations of filling and emptying in nearby plants are produced, the filling will be stopped, and it will be done when the emptying of the other plant is completely finished.

Records

The analysis provided by the compost suppliers or the analysis done to the compost will be registered. The dates of filling and emptying of the cultivation plants will also be recorded. In addition, the incidences occurred during this stage and the corrective measures applied will be annotated.

Stage 6: Pre Fruiting-Induction

At this stage, the mycelium continues the casing layer colonization. The initiation and development of carpophores take place at the end. The vegetative growth conditions are maintained for about 8 days, with limited ventilation. After that, a sudden decrease in the temperature to 12–20 °C is done, accompanied by strong aeration ($\text{CO}_2 \leq 0.08\%$). The relative humidity is also reduced, remaining at 85–90 %. It is recommended not to water when the primordia size is lower than a pea. The presence of certain bacteria (*Pseudomonas putida*, among others) in the casing layer can help to develop fruiting [18]. The vegetative growth is favored by a high C/N ratio while the fruiting needs a lower ratio. At this stage, preventive treatments with fungicides and insecticides are usually carried out to prevent fungal and insect proliferation.

Hazards

The main hazards in this stage may result from different sources, in particular the hygienic and sanitary conditions of the casing layer applied in the previous stage. The use of unauthorized fungicides and insecticides, or in higher doses than recommended, or without respecting the security period will become the main hazards at this stage. The inadequate quality of irrigation water can also represent a hazard for the cultivation.

Preventive measures

The application of authorized phytosanitary treatments is the main preventive measure. The most widely used fungicide after application of the casing layer in the case of mushroom cultivation is the Procloraz (45 % SC and 46 % WP), while the most common insecticide is the Diflubenzuron (25 % WP). In addition, the analysis of the irrigation water must be done to ensure the adequate quality.

Critical limit

The critical limit is defined by the use of authorized phytosanitary products, applied in the correct dose, and respecting the security periods established for the use. This information must appear in detail on the labels of these products and must be taken into account previously to their use.

Monitoring

The use of authorized phytosanitary products, the doses applied and the fulfillment of the security periods established for their use will be monitored. Tracking plans in the collected mushrooms will be done to verify the possible presence and levels of phytosanitary products residues.

Corrective measures

When the application of fungicides and insecticides are not effective, the treatment schedule will be corrected. If the problem persists, the product will be replaced by a similar and authorized one. When the presence of pesticide residues are detected in mushrooms at levels above those permitted, the mushroom harvested will be destroyed according to the monitoring plans for pesticide residues in crops implemented by the corresponding authorities.

Records

The programming of phytosanitary treatments will be recorded. The records will include the annotation of the products used, their active ingredients, the type of treatment, and the moment of application, doses, security periods and toxicology. In addition, the incidences occurred during this stage and the corrective measures applied will be annotated.

Stage 7: Harvesting

The harvesting of the mushrooms of the first flush begins about 16–20 days after the application of the casing layer,

depending on the species, the cultivation method, the thickness of the casing layer, etc. The collection of the successive flushes is done with intervals of 7–10 days (up to five flushes, although it is not usual to exceed three to avoid the incidence of pests and diseases that are produced at the end of large cultivation cycles.). The containers in which the mushrooms are collected must be as practical as possible, and with smooth walls to avoid the damage in the mushrooms [19]. The application of phytosanitary treatments may be necessary between consecutive flushes, thus the main hazard of this stage is the use of unauthorized products, with higher doses than allowed, or without respecting the recommended security periods. Therefore, the preventive measures, the critical limits, the monitoring, the corrective measures and the records to be applied will be similar to those of the previous stage (pre fruiting-induction).

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