Chapter 2
The Reduction of Microbial Spreading: Little Details, Great Effects

Abstract The eradication or the limitation of microbial contamination into food industries and dedicated warehouses may be reduced by means of a multidisciplinary and integrated management approach. In the ambit of the so-called 'Hazard analysis and critical control points' plan, different instruments and procedures may be applied with interesting results. The reliable selection of raw ingredients, including reusable (recycled) waters and packaging materials, has to be perceived as the first pilaster of a well-designed and implemented HACCP plan. Moreover, other aspects correlated to the prevention and minimisation of microbial spread into food production areas have to be considered: the separation between different areas in the same industry; the problem of cross-contamination between different lines, including the necessity of limiting aerosolised suspensions; the possible survival (and transfer) of microscopic life forms via cloths, hands, utensils and food refrigeration equipment; the creation and implementation of correct cleaning and sanitising procedures. These aspects of the modern challenge to microbial spreading and contamination episodes in food industries are briefly discussed in this chapter.

Keywords Aerosol · Biofilm · Protobiofilm · Food business operator · Good manufacturing practice · HACCP · Microbial spreading · Purified water

2.1 Basic Strategies Against Microbial Spreading in Food Industries: An Overview

At present, the eradication or the limitation of microbial contamination in food industries and dedicated warehouses (Sect. 1.5) may be at least reduced by means of the following techniques and/or procedures (Evans et al. 2004; Scott and Bloomfield 1990):

(1) Correct selection of raw ingredients and packaging materials;
(2) Separation between different areas;

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(3) Prevention of cross-contamination episodes between different lines dedicated to the production of dissimilar foods;
(4) Prevention of survival and transfer of microscopic life forms via cloths, hands and utensils;
(5) Prevention of microbial contamination by food refrigeration equipment;
(6) Use of thermal processing treatments and/or preserving technologies (smoking, salting, etc.);
(7) Use of purified water and modern techniques (sonication, etc.);
(8) Purification of atmospheric gases and prevention of aerosolised suspensions;
(9) Creation and implementation of correct cleaning and sanitising procedures.

This list covers many of the modern strategies for the limitation of microbial counts in foods. Unfortunately, each approach or method may reduce a specified microbial risk but other failures can occur at the same time (Sect. 1.5). The aim of this book is to give a reliable overview of different strategies with related advantages and drawbacks.

2.2 Correct Selection of Raw Ingredients and Packaging Materials

Basically, the main source of microbial contamination of food products (pathogen and degrading life forms, viruses, etc.) should be researched in the ambit of the primary production.

This approach is particularly important when speaking of pathogenic contamination. Because of the remarkable importance of certain microorganisms in connection with peculiar outbreaks such as the recent 2011-*Escherichia coli* crisis in Europe (Montanari et al. 2015; Pisanello 2014), the identification of original contamination sources is one of the main pilasters of the 'hazard analysis and critical control points' (HACCP) approach to the problem of food production and distribution. As an example, the detection of *Listeria monocytogenes* in different foods (meat products, etc.) may be correlated with environmental samples, including vegetation, faeces and meat (Fenlon et al. 1996). The same can be easily affirmed with relation to *Campylobacter* colonisation in poultry products (Wagenaar et al. 2008) and the recent *E. coli* O157:H7 outbreaks. With regard to the last microorganism, the use of contaminated water during irrigation, propagation or washing (Fig. 2.1) has been considered since 1999 (Food and Drug Administration 1999; Kirby et al. 2003).

Generally, the main environmental sources of microbial contamination are recognised as follows (Kirby et al. 2003):

- Water intended for primary production facilities (aquaculture, irrigation, etc.);
- Water intended for food processing plants and operations (bottling, cooling, washing, production of ice, cleaning, sanitisation, etc.);

Fig. 2.1 The detection of *Listeria monocytogenes* and other pathogens such as *E. coli* O157:H7 in different foods may be correlated with environmental samples, including vegetation and waters. The use of contaminated water during washing processes has been considered since 1999

- Recycled water;
- Feeding products intended for animal nutrition;
- Contaminated raw ingredients for food production;
- Contaminated food packaging materials and objects;
- Contaminated machinery and related parts;
- Contaminated air (aerosolised suspensions);
- Other causes, including hygienic conditions of factory workers;
- Surface water flow (pattern, drainages, water stagnation, etc.);
- Collection drains/discharges and sewerage);
- Proximity of uncontrolled waste dumps.

The matter of water decontamination is discussed here in detail with other measures concerning the segregation of different areas and aerosolised suspensions. Moreover, contamination by raw materials and feeding products should be discussed in the vast ambit of HACCP strategies (Chap. 4). In addition, the hygiene of food-contact approved materials for machinery is described in Chap. 3.

In regard to water supplies, normal countermeasures are explained briefly as follows.

Water treatments are carried out mainly with the aim of protecting consumers and foods from microbial pathogens and from chemical and physical impurities (Kirby et al. 2003). Actually, the scope should also comprehend the limitation of microbial spread from degrading life forms without dangers for human health. Generally, the treatment of waters for food production (with the exclusion of wastewater) concerns the following operations (Kirby et al. 2003; World Health Organization 1996):

- Coagulation
- Sedimentation
- Filtration
- Other advanced treatments (activated carbon, ion exchange, membrane filtration, reverse osmosis, etc.)
- Final disinfection (oxidation, ultraviolet light, heating processes, use of caustic substances, etc.).

According to current HACCP approaches, a sufficient supply of potable water is strictly required (Kirby et al. 2003; World Health Organization 1996). For this reason food plants without primary production have to rely on this important 'ingredient' (Poretti 1990). Potable water is also present in foods after incorporation: one of these situations concerns the production of *pasta filata* cheeses. Original raw materials, cow's milk curds, are 'washed' in hot water, but a certain amount of water is adsorbed by proteins (Barbieri et al. 2014a). Consequently, publicly available potable waters are often used in food plants. On the other hand, food business operators (FBO) without available waters may be forced to reuse or recycle their water supplies when allowed by HACCP plans. In fact, the use and reuse of waters in food production and processing steps should be evaluated using the HACCP approach because of the clear and well-demonstrated connection between water and food-borne diseases (Kirby et al. 2003). Anyway, recycled or re-used water should not affect food safety and the general (accepted) quality of product (Codex Alimentarius Commission 2000). For these reasons, a certain amount of analytical tests are required with the aim of assuring safety and quality, depending on risk assessment and HACCP evaluations. Because of the importance of the final destination (reuse) of water, the frequency of analyses should be carefully evaluated. In addition, reused water has to be sanitised when intended for container cooling operations (Kirby et al. 2003).

Particular attention should be given with regard to water decontamination in food plants. In fact, the complete purification or production of potable water is not possible in several food production environments. For this reason, FBO can reasonably use only a few selected methods for decontaminating water supplies from the microbiological viewpoint at least among these systems (Amjad 1993; Casani et al. 2005; Gupta and Ako 2005; Huang et al. 2008):

- Sedimentation and filtration
- Ion exchange
- Ultraviolet (UV) light
- Reverse osmosis
- Membrane filtration
- Lime treatment
- Flocculation with selected aid such as guar gums (with relation to chemical purification)

Hydrogen peroxide + Silver ions generator

Fig. 2.2 Water decontamination in food plants has to be considered as one of the main pilasters of food safety. The complete purification or production of potable water is not possible in several food production environments. For this reason, food business operators can reasonably use only a few selected methods for decontaminating water supplies from the microbiological viewpoint. One of these strategies is the use of innovative systems such as hydrogen peroxide and silver ion generators

- Complete disinfection (oxidising chemicals, UV light, caustic chemicals, heating processes, etc.)
- Innovative systems (Gurnari 2006): electrolysed water, ozonisation, synergic ozonisation and ultraviolet light (O_3–UV) treatment, hydrogen peroxide and silver ions, etc. (Fig. 2.2).

Other methods may be the use of selected antimicrobials in waters: chitin, chitosan and their derivatives such as hydroxypropyl chitosan have been already proposed (Kamble et al. 2007; Onsosyen and Skaugrud 1990; Shahidi et al. 1999; Xie et al. 2002) for the purification of water (removal of metallic cations, pesticides, polychlorobiphenyls and phenols and dyes) and the observed antibacterial activity. However, the full application of these chemicals for water supplies in the industrial field should be evaluated in the future because of economic implications and technological difficulties.

At present, physical and chemical methods appear the most used technologies for the prevention of water contamination (and recontamination) in food plants. However, it should be noted that the preferential direction seems to favour synergic systems: the ‘oxidising chemicals/UV light/heating process’ combination and other systems appear as good choices in big and medium-sized industries. On the other hand, little plants seem to prefer one single apparatus instead of synergic disinfection methods, with the possible addition of chlorinated water at some points in processes. With regard to these industries, the best strategy is always correlated to the microbial (or chemical) risk on the one hand, and the necessity of minimising water consumption and wastewater discharge rates (Gil et al. 2009). The reduction of wastewater rates is generally dependent on the employed disinfection technique (Gil et al. 2009; Ölmez and Kretzschmar 2009). On the other hand, the best disinfection technique should be defined on the basis of the following factors (Gil et al. 2009):

(a) Chemical contents
(b) Water consumption
(c) Water use (example: washing)
(d) The desired result in terms of quantitative reduction (log units) of microbial counts and qualitative eradication of targeted bacteria (*E. coli* and F-specific coliphage MS2, *Salmonella* spp., *L. monocytogenes*, *Pseudomonas fluorescens*, *Enterobacteriaceae*, *Aeromonas* spp., Hepatitis A, natural microflora, etc.)
(e) Diffusion of supplied water along the process flowchart
(f) The final food product
(g) Water supply system and its source (Spica et al. 2012).

2.3 Segregation of Raw Materials

According to HACCP principles and the most recent quality standards (Barbieri et al. 2014b; Materia et al. 2009; Parisi 2002; Parisi et al. 2009a, b, c; Stilo et al. 2009), the microbial risk of food contamination by different raw ingredients and materials may be managed and limited by means of segregation procedures. In detail, the delimitation of food plants, warehouses and retail spaces into high/low-risk areas (or clean/dirty areas) may be very useful (Bratt 2010) when speaking of the eradication or limitation of the following phenomena (Sect. 2.1):

- Cross-contamination of raw ingredients for food production;
- Cross-contamination of packaging materials and objects contacts;
- Cross-contamination of processing machinery and related parts;
- Air contamination (aerosolised suspensions);
- Contact time and exposure time;
- Micro-climatic conditions.

Substantially, the separation of different rooms or warehouses should be decided depending on the material typology (raw ingredient for food production; raw material for packaging processes; etc.) and the subdivision between different materials into the same typology (examples: chilled storage; 20–25 °C—storage; dry environments, etc.). Clearly, every decision depends mainly on the risk assessment of all possible dangers.

The subdivision of food plants and warehouses in different areas influences the quality and safety of raw and ready-to-eat foods. In detail, good manufacturing practices (GMP) should at least concern the following factors (Santana et al. 2009):

(a) Suitable storage, in terms of the definition and practical implementation of times, temperature, handling and protection for raw ingredients (including additives) with some effect on the quality and safety of the final product(s). This point should also include the separated storage by the type or group, with the use of non-wooden pallets or treated wooden packaging materials such as heat-treated or fumigated objects with methyl bromide (Dwinell 2004; Shahidi 2011; Woodroffe 2010);
(b) Suitable storage of time, temperature, handling and protection against environmental agents (dust, foreign bodies, UV light, heating, excessive humidity, etc.) for packaging materials;
(c) Suitable storage for food-contact materials and objects with regard to food processing machinery (examples: plastic moulds, pliable metallic plates, etc.);
(d) Linear flow of food processing in one direction only, with the aim of avoiding cross-contamination episode between different working lines and related food intermediates;
(e) Suitable storage of hazardous substances for cleaning, sanitising substances and pest control compounds (insecticides, acaricides, etc.);
(f) Suitable and separated storage for food allergens and genetically modified organisms (GMO) foods (Hino 2002; Van der Vorst 2006). Additionally, adequate labelling measures are strictly needed in food industries when speaking of food commodities without clear allergenic or GMO identification (Hino 2002; Trienekens and Zuurbier 2008);
(g) Exposure to electromagnetic fields (or ionisation generator).

When speaking of unpackaged (unprotected) food commodities, the subdivision in different areas such as ‘high risk’ and ‘high care’ zones (Voltmer 2012) should also be based on the assessed risk. As an example, significant *Listeria*-food safety risks can justify the localisation of a detailed high risk or high care zone (Voltmer 2012). Anyway, the ‘high risk’ zone concerns only areas where processed (food) products are unpackaged and/or is still open after a treatment which eradicates or reduces significantly the risk. On the other hand, ‘high care’ zones concern only areas where (food) products need protecting in order to avoid further contamination after a treatment which does not eliminate completely the risk (Voltmer 2012). The correct decision has to be taken on the basis of a ‘production zone decision tree’ (BRC 2012). In addition, ‘low risk’ areas concern zones at room temperature where stored foods are not considered significant ‘culture media’ for the proliferation of pathogens (BRC 2012).

2.4 Segregation of Packaging Materials and Equipments

Food contamination may also occur via food packaging materials and objects. The nature of 'passive microbial contamination' vehicles is known in the scientific literature when speaking of food containers and correlated parts (Brunazzi et al. 2014; Parisi 2012, 2013). However, the problem of microbial spreading in foods may include each potential food-contact surface and material in food plants, warehouses and retail structures. For example, the diffusion of *Listeria* spp. has been extensively studied in different environments where the presence of non-edible surfaces is the common point (Centers for Disease Control and Prevention 2011; Gandhi and Chikindas 2007; Tompkin et al. 1999; Tompkin 2002).

For these reasons, food packaging materials and objects should be adequately stored in separated warehouses, according to the most recent quality standards (Parisi et al. 2009b, c). Adequate sealing and/or protecting procedures for the storage of 'in-use' food-contact materials and objects should be established and fully implemented. In fact, the possible occurrence of peculiar biofilms (microbial agglomerations on plastic polymers or metallic surfaces) cannot be excluded before production. Cleaning and sanitising methods should be sure enough with relation to this risk. On the other hand, the possible occurrence of the formation of proto-biofilm agglomerations during certain cheese productions has highlighted the capability of survival of certain microbial species even under drastic thermal conditions. As a consequence, non-edible food-contact surfaces should be considered as potential vehicles of microbial contamination in different environments (Centers for Disease Control and Prevention 2011).

2.5 Aerosolised Spreading

Another source of cross-contamination between different raw materials, ingredients, working lines and products is always connected with the so-called 'aerosolised' matter. Briefly, every food plant is a sort of 'microcosm'. A number of possible matter transfers can occur at the same time into the same room or between two different (and far) areas, depending on the following factors (Burfoot 2005):

(a) The rate of generation of airborne particles;
(b) Particle dimensions and related speed;
(c) The direction of air flows in a single room;
(d) Exposure areas of food-contact surfaces (including walls and ceilings) and unpackaged/intermediate foods in high care areas;
(e) The peculiar flow of food processing (one direction only should be preferable);
(f) The number of concomitant food processes;
(g) The number of moving machinery parts, including hand trucks, different carriages, fork lifts, etc.;

(h) The number of working operators (blue workers should be always considered as potential contamination vehicles);
(i) The correct procedure for washing in food processing plants (the higher the amount of sprayable water, the higher the potential formation of aerosolised suspensions with or without living microorganisms);
(j) The correct disinfection of cleaning systems;
(k) The air-handling system, natural or forced, the numbers of air diffusors; the speed of threads, the dehumidification/humidification capacity; the source of the air treatment in place;
(l) The maintenance of the filtration system.

In general, aerosols can also occur in closed areas such as chillers and other warehouses. Should this be the situation, the problem could appear simpler because of the 'staticity' of microbial colonies in restricted spaces. Unfortunately, several failures seem to be correlated or originated into restricted zones (Materia et al. 2009), even at low temperature (2 ± 2 °C).

With regard to cleaning tools and their management, it has been recently reported that high-pressure washdown systems may be the cause of aerosolised suspensions with consequent problems of cross-contamination (Parisi et al. 2009b). The same situation may also occur when manual cleaning instruments are not controlled and sanitised (Parisi et al. 2009c). For these reasons, forced ventilation and/or other strategies are needed if a remarkable number of viable particles are detected in food plants (Burfoot 2005). Otherwise, excessive aerosolised suspensions may cause the formation of durable biofilms (*Salmonella* spp., etc.) on food-contact materials and objects in food plants and small rooms such as kitchens (Chmielewski and Frank 2003; Humphrey et al. 1994).

The use of similar techniques in food plants such as dairy industries may be very useful (Gibson et al. 1999). However, several authors recommend considering cautiously collected results 'on ground' in certain situations, depending on the used instruments (Kang and Frank 1990).

In conclusion, the management of the above-discussed factors can be helpful. On the other hand, the prevention of air contamination should be efficacy obtained when forced ventilation systems are used and regularly inspected with the aim of preventing malfunctions and/or possible (and sudden) formation of aerosolised suspensions at some point in flow processes.

Finally, the proper maintenance of the sensors and control units inside the governed climate, especially in confined areas, has to be considered (Brera et al. 2013).

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