Food safety research underpinning food service systems – a review

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Abstract

Food service systems allow the decoupling of food production from service and offer economies of scale. However, the multiple steps in processing introduce additional safety risks in comparison with the traditional preparation. Operators need to be aware of the preservation principles and the type of data available in food safety research. This paper provides justification and describes the link between different types of studies in the field: surveys of background microflora, challenge studies, food safety design, predictive modelling, hazard analysis critical control point (HACCP) and good manufacturing practices (GMP). The needs and directions for further research are identified.

Introduction

Modern food services are facing formidable and often conflicting challenges: consumers demand higher quality food, governments require the guarantee of safety and owners/shareholders seek increased profits. In addition, environmental considerations are becoming more important. Both the institutional and commercial sectors rely heavily on economies of scale and the use of ‘hard’ or equipment-based technologies. The developments in engineering and packaging offer a wide range of options for bulk food production. Cook-hot, hold, cook-freeze and cook-chill (traditional and packaged) methods have been used to provide a ‘time buffer’ between production and consumption.

Often, central production units (CPUs) have spare production capacity to supply external customers and the retail sector (New South Wales Health Department 2005). The lack of confidence in food safety and limited chilled distribution channels are some of the reasons of this under-utilization. Consequently, even large organizations, such as Eurest Australia (http://www.eurest.com.au/Home/index.html) and Gourmet Foods in the US (Hauck 1992), freeze their products instead of merely chilling them. In the UK, nearly 80% of sous-vide (cooked-in-a-bag) products are frozen (Sheard 1999). Research on strengthening the food safety design offers significant practical advantages in terms of consumer confidence, prevention of overcooking and potential reduction in processing/storage costs.

However, the legislative requirements are the main drives of research in food safety. The Australian Food Standard Code (ANZFA 2002) stipulates that all food service businesses must develop a hazard analysis critical control point (HACCP) – based food safety programme. Numerous other bodies around the world, the Canadian Code of Recommended Manufacturing Practices (Agriculture Canada 1990), the US Food & Drug Administration (2001), the Advisory Committee on the Microbiological Safety of Food 1995), the European Chilled Food Federation Botulism Working Party (Gould 1999) and the Food Linked Agro-Industrial Research European Commission (1997), address the food safety risks of long shelf-life (LSL) cook-chill technologies including sous-vide and hot-fill.

In general, the focus of studies on food safety followed the development of different systems – cook-freeze in the 1960s, traditional cook-chill in the 1970s and LSL cook-chill in the 1980s. At present, there is no journal dedicated solely to food safety aspects of food service operations. However, leading mainstream food science and technology publications (Food Control, International Journal of Food Microbiology, Journal of Food Protection, Food Safety and others) often cover...
topics related to food services. In this paper the preservation principles, the need and pathways of research on food safety are analysed in the context of food service operations. The surveys of background microflora, challenge studies, studies on food safety design, predictive modelling, (HACCP) and good manufacturing practices (GMP) are reviewed.

The pathways in food safety research

There are three types of food service products in terms of their microbial status. The first type is chilled uncooked products (salads, sandwiches, etc.) with the whole range of food-associated microflora (bacteria, moulds and yeasts), which are often harmless and even can have a bio-protective effect against food poisoning or spoilage microorganisms (FPSOs) (Jay 1995). The second type is the traditional or ‘open tray’ products (cooked and not packaged). Cooking would destroy indigenous yeast, moulds and the majority of vegetative bacteria. Such products would have some surviving indigenous spore-formers, which can germinate during inadequate storage, as well as the microflora introduced during consecutive handling. The third type is the packaged LSL cook-chill products, which together with controlled atmosphere packaging (CAP) and modified atmosphere packaging (MAP) are classified as ROP (reduced oxygen packaging) products by the US Food & Drug Administration (2001). The Administration recognizes Bacillus cereus, Salmonella spp., Staphylococcus aureus, and Vibrio parahaemolyticus as the FPSO of significance for ROP and warns that Salmonella spp., Campylobacter spp., and Brucella spp. can survive in such products for long periods of time. All these except the spore-forming B. cereus would not survive pasteurization in the LSL cook-chill foods.

The microbial status of the LSL cook-chill foods would depend on the degree of heating – each increase in the processing severity (cooking time-temperature combinations) results in the destruction of more species of pathogens. If the heating is lower than 10 min at 90°C, any temperature abuse is extremely dangerous as psychrotrophyc Clostridium botulinum, one of the spore-forming pathogens capable of surviving mild pasteurization, can grow and produce toxin under refrigeration (Brown & Gaze 1990; Brown et al. 1991; Rodgers 2002). Consumption of as little as 30–100 ng of botulinum neurotoxin can be lethal (Peck 1997).

Food service operators should be able to differentiate between the risks associated with the type of raw materials (Salmonella spp. in chicken, Vibrio parahaemolyticus in seafood, etc.) and preparation technologies (vegetative microflora in traditional vs. spore-formers in LSL cook-chill). When managers commission biological tests or verification studies they need to appreciate the hierarchy of different levels in food safety research – the data generated from studies at the lower levels form a base for the higher level. Figure 1 shows that there are two streams of research: the studies analysing the microflora in the product itself and the studies describing the surrounding environment such as air, water and food contact surfaces. The former are developed on the knowledge of background microflora and the effect of preservation factors (challenge studies). Both shelf-life studies and HACCP are based on such information. Predictive modelling is a statistical tool, which is used to quantify these effects. The studies on the effectiveness of cleaning programmes, product flow (facility design), personal hygiene rules and staff training support GMPs, which, in turn, support HACCP (Fig. 2). The lack of proper equipment and incorrect layout, for example, were the main obstacles to efficient HACCP management (Paniello & Quantic 2001).

Background microflora surveys

Unlike managing food safety risks from chemical pollutants, when the simple removal of the source of contamination is sufficient, managing microbiological risks requires the knowledge of the types and population levels of ubiquitous bacteria. The studies on background microflora are conducted to enumerate and identify FPSOs in raw materials and the final product; sometimes the sources of contamination are traced by matching the strains with those isolated from raw materials or the environment. Post-process contamination of cook-hot-hold meals prepared and distributed by a CPU to schools in Argentina (Tessi et al. 2002), for example, originated from food handlers and kitchen environment. The spore-forming bacteria in LSL cook-chill meals, which represent pathogenic and spoilage risks (Lopes et al. 1999), were traced to dry ingredients such as milk powder and starch (Carlin et al. 1999). In sous-vide fish-based products, C. botulinum and Listeria monocytogenes (in the case of under-processing) were identified as the most important pathogens (Rosnes et al. 1999).

The ROP products are protected from re-contamination by packaging. In general, studies show negligible background microflora in a wide range of LSL meals (Nyati 2000; Rybka et al. 2001). However, the population levels depend on the storage temperature. Hansen et al. (1995) showed the difference in counts of spore-formers in sous-vide beef during storage at 2 and 10°C (Fig. 3). Another type of bacteria, lactic acid bacteria (LAB) are frequently isolated from a variety of LSL meals (Shamsuzzaman et al. 1995; Simpson et al. 1999).
These are unexpected results as LAB do not form spores, but being Gram-positive are relatively heat resistant.

It should be noted that studies on the incidence of pathogens are rarely commissioned by food services as they require a large sample size, which is often cost prohibitive. The data on a prevalent commodity type (seafood, chicken or minced meat, for example) can be found in the mainstream food microbiology research or the published results commissioned by food manufacturers.

**Challenge studies**

Challenge studies involve the inoculation of food with FPSOs, which are usually identified in the background.
microflora surveys. An inoculated product can be subjected to the intended steps in processing – cleaning, peeling, cutting, heating, portioning, storage, distribution, rethermalization, retailing, service, etc. Alternatively, FPSOs can be challenged with additional controlling factors, which are physical, chemical or biological in nature. With the developments in the LSL cook-chill technologies, non-thermal preservation hurdles, such as lactate, irradiation, bacteriocins and protective cultures, have been tested (Rybak-Rodgers et al., 2001). In practice, challenge studies are used to establish processing parameters, such as those described in the industry codes (New South Wales Health Department, 1998a,b,c,d), verify the adequacy of processing and extend the shelf-life of a product.

The examples include the adaptation mechanism of *Basillus* spp. to thermal stress (Arinder et al., 1999; Carlin et al., 1999) as well as the survival and growth of *Escherichia coli*, *L. monocytogenes*, *Salmonella* and *B. cereus* at chilled temperatures (Gibbs, 1999). The minimal heating requirements of 2 min at 70°C for traditional cook-chill system (New South Wales Health Department, 1998c) are based on the survival of *L. monocytogenes* tested by Gaze et al. (1989); the storage temperature of 3°C and the shelf-life of 28 days for LSL meals (New South Wales Health Department, 1998d) on the study on the minimal growth temperature (3.3°C) and ‘time to toxin’ (30 days) for *C. botulinum* by Hatherway (1992).

Challenge studies require complex experimental protocols and are not commissioned by food services routinely. Only when the process does not have the proper time/temperature controls to guarantee the safety of the product, as can be the case with the LSL cook-chill meals, such studies are needed. Consequently, reports addressing the danger of botulism dominate the field. The examples include the survival of *C. botulinum* during cooking (Fernandez & Peck, 1997) and storage (Brown & Gaze, 1990; Brown et al., 1991). The poor growth of this pathogen in sous-vide meals was reported by Hyytia-Trees et al. (2000) and Rodgers (2002); the low temperature (<5°C) and pH (<5.5) were adequate to control growth and toxin production.

Food manufactures have long been designing products to suit their operational requirements (mostly shelf-life) by application of preservation hurdles. This is a novel concept for food service operators accustomed to cooking and serving meals without delay. The concept of LSL in food services allows limitless opportunities in terms of centralized food production. The extension of shelf-life can be achieved by a variety of methods. The ‘double-heating’ method was used commercially by Naka system (Light & Walker, 1990) in the 1960s – it resulted in the over-cooked and ‘tired’ product quality. ‘Intelligent’ combinations of hurdles are possible when several antimicrobial factors of low intensity provide safety without affecting the sensory quality of products.

The ROP meals can be irradiated after the packaging step (Grant & Patterson, 1995). The main advantage of irradiation is that it does not cause significant quality deterioration; the main disadvantages are the need for expensive equipment and the fact that it is not compatible with the ‘fresh’ image of food service products. For the same reason, the use of chemical preservatives is excluded. Other non-thermal processing technologies, such as MAP and hydrostatic pressure, are not effective against spore-forming FPSOs. The use of natural ingredients with antimicrobial properties or their derivatives is a more ‘natural’ solution. Spices (clove, thyme, black pepper, pimento, origanum, garlic, onion, cinnamon) (Ismael & Pierson, 1990a,b), essential oils of sage, turmeric, mustard and fenugreek (Packiyasothy & Kyle, 2003) as well as sodium lactate (Meng & Genigeorgis, 1994) have been tested. However, high effective concentrations of terpenoid compounds in spices (Packiyasothy & Kyle, 2003) and the aftertaste of sodium lactate affect the flavour of food.

Bio-preservation, on the other hand, can be applied to any product. Bacteriocins (substances produced by Gram-positive bacteria against closely related species) are effective at very low concentrations. In many developed countries, the use of bacteriocins is limited by legislation. In the US, for example, only Nisin (nisin) is allowed in cheese and liquid eggs. Fermented products that are less concentrated can be added to meals without approval. However, like spices and lactate, such applications may cause sensory changes. Live
LAB, on the other hand, do not affect taste (Rodgers et al. 2002), are recognized as safe and offer the unique temperature-sensitive inhibition – inhibitory substances are produced only when a product is subjected to temperature abuse.

Protective cultures, the bacteriocin-producing Lactococcus lactis spp. lactis and Pediococcus pentosaceus, prevented the botulinum toxin production in seafood chowder stored for 10 days at 10°C (Fig. 4). The main disadvantage of bio-preservation is the need for a complex development process starting with the screening of potential ‘candidates’ for protective cultures and finishing with sensory evaluation and scaled up production (Rodgers 2003). The practical difficulties include the heat sensitivity of LAB (during the hot-filling step) and the need for legislative approval in such countries as Australia.

Thus, operators need to be aware of the existence of other controlling factors apart from time/temperature combinations. The potential benefits include the ‘relaxation’ of processing parameters – decreased heating and increased storage temperature. This would result in the cost of energy savings. A CPU would be able to deliver the product to the satellite kitchens through refrigerated (5–7°C) distribution channels rather than keeping a fleet of specialized chilled (<3°C) tracks. The reduction in the severity of cooking would also improve the quality attributes of meals with heat sensitive ingredients (eggs, cheese, poultry, seafood and leafy vegetables).

**Predictive microbiology**

Predictive microbiology is one of the modern developments which can make food safety design feasible in food service settings. It is based on the principles of statistics and food microbiology. The fact that the microflora of non-preserved foods is dynamic – it reacts to temperature changes – offers the possibility to construct predictive models describing the growth patterns of bacteria. The latter depends on a relatively small number of factors, for example, temperature, food composition, initial contamination level and the presence of any additional antimicrobial factors.

The models used in predictive microbiology, such as the Modified Gompertz equation, reflect the non-linearity of microbial inactivation and growth as a function of time. The scarcity of raw data on microbial populations in food services can be overcome by the application of artificial neural networks (Geeraerd & van Impe 1999). The interconnections between different factors affecting microbial growth are treated similarly to the responses of the human nervous system.

Miles & Ross (1999) listed potential applications of predictive modelling in HACCP management: (i) to show which FPSO can grow on the product; (ii) to define the processing parameters to achieve death or stop the growth of a FPSO; (iii) to test ‘what-if’ scenarios with different product formulations and processing parameters to see if alterations will allow a new hazard to emerge; and (iv) to establish the suitability of a product after a loss of control at a CCP, such as under-cooking or a break-down of a cool room.

The accuracy of the models is the major limiting factor in the practical applications of predictive microbiology. Despite the latest developments, the programmes are not reliable enough to verify a new food service system without ‘real-life’ challenge studies. The main fundamental problem is the fact that the data used for the model development are mostly derived from microbiological broths. Robins & Wilson (1994) demonstrated that the growth pattern of bacteria in solid and semisolid media would be slower. On the other hand, it would be impossible to develop a separate model for each product type. Consequently, commercial programmes such as the FMM (Food MicroModel, UK), PMP (Pathogen Modelling Program, USDA http://www.arserrc.gov/mfs/pathogen.htm) and **Food Spoilage Predictor** include a warning that the users have to validate the models for each product. In food services, this would be impossible with ever-changing range of recipes, preparation methods and storage conditions.

The studies on accuracy and validation of the models comprise one of the fields of research in predictive...
microbiology. The FMM predictions, for example, were conservative when tested in the variety of LSL cook-chill meals (Hyytia-Trees et al. 2000; Rodgers 2002). In general, the shelf-life predicted by the FMM was shorter than those by PMP (Hyytia-Trees et al. 2000). The PMP showed a good ‘fit’ in seafood chowder only after nine days of storage at 10°C (Fig. 5) and was more sensitive to pH than the FMM (Rodgers 2002).

Operators should also be aware of the wider range of possible applications of modelling: (i) operation design; (ii) heat penetration patterns based on the shape of a heating unit and the properties of food; and (iii) functional properties of new ingredients in terms of their effect on product texture or health benefits based on their chemical structure, and so on.

Haccp

The field of research on HACCP covers the ways of controlling FPSOs. In tourism, for example, two types of pathogens are recognized in this respect: those controllable by the tourism industry through maintaining high standards of food safety; and those whose control does not lie primarily in the domain of the tourist industry, such as street vendors or rural farm visits (MacLaurin 2001). HACCP deals with the ‘fate’ of the product during processing and should not be confused with hygiene and sanitation and other GMP programmes (Fig. 2). HACCP is situated at the core of the pathways in food safety research (Fig. 1). The whole field of food microbiology concerned with studying pathogens is relevant to HACCP. The codes mentioned earlier (New South Wales Health Department 1998a,b,c,d) are the prototypes of a HACCP table specifically designed for different food service systems. The verification of HACCP typically involves final product testing against recognized microbial standards. Such validation is needed for a new or modified food service system not described in the industry codes.

There are other ‘soft’ aspects of HACCP, which are not directly based on research in microbiology and, consequently, not listed in Fig. 1. These aspects reflect the nature of HACCP as a quality management tool and include the elements of risk assessment as well as studies on the effectiveness of food safety legislation and HACCP-based policies, the link with the ISO 9000 and TQM (Total Quality Management) programmes, the organizational measures (Snyder 1995) and the implications on human resource management.

The quantification of potential risks would guide operators in the allocation of funds to CCPs with higher impacts. The methods in risk assessment include sophisticated statistics coupled with computation. The ‘Monte Carlo’ simulation, for example, is capable of generating the probabilities of the range of possible outcomes. Bayesian Belief Networks (Barke et al. 1999) provide transparent representation of complex scenarios with many uncertain quantities. These tools are important when managers have to prioritize the spending of limited resources.

Managerial protocols for HACCP in food services do not differ fundamentally from generic risk assessment approaches used in other sectors of hospitality – on cruise ships, for example (Fig. 6). Although, the matrices for risk assessment in food service applications would have the hazards of different nature. The scores are allocated for the categories of food (higher for seafood and lower for mayonnaise, for example), the way food is prepared (higher for a process with many steps) and the frequency of use (Coleman & Griffith 1998).

The managerial aspects extend to practical (staff reluctance to work in low temperature environments, inability to monitor core temperature of cooking for the cooked-in-a-bag products, cool-room alarm activation set at higher temperatures to account for the defrost cycle, etc.) (Rybka 1999) and technical (Table 1) barriers in HACCP implementation. There are also human resource management aspects of HACCP: (i) the development of mutual understanding between the staff and environmental health officers (UK) or food inspectors (Australia); (ii) the need for leadership and the change of old habits/attitudes; and (iii) staff motivation and supervision (Panisello & Quantic 2001). It can be concluded that research on HACCP is positioned on the interface between funda-
Figure 6  The formal safety approach for cruise vessels. Adopted from Lois et al. (2004). Hazard identification (HAZID).

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<th>Table 1  Technical barriers in HACCP implementation in food services</th>
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<td><strong>Barrier</strong></td>
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<td>Company size</td>
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<td>Company’s customer</td>
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Compiled from Panisello & Quantick (2001)

mentals of food microbiology and management practices.

**Good manufacturing practices**

Environmental microbiological studies are not unique to food services; food industry and infection control agencies use similar approaches. Filtration is used for enumeration of bacteria in water. Swabs are taken from different surfaces to assess the effectiveness of hygienic practices including cleaning. For example, the critical areas harbouring pathogens were personal protective equipment including oven mitts and potholders (Michaels et al. 2002). Floor mats and footbaths were contaminated with *L. monocytogenes*, a pathogen of particular significance in cook-chill processing (Klausner & Donnelly 1991).

Surfaces can be inoculated or challenged with an indicator organism, subjected to cleaning and then swabbed. Meredith et al. (2001) used this approach to study the potential spread of pathogens during preparation of chicken casserole. Considerable contamination was found with hand washing being an effective prevention measure. Plate count is the technique most often used to assess the effectiveness of cleaning, the validation of rapid methods in testing for microbial

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contamination (ATP bioluminescence or analysis for proteins) as well as the accuracy of visual inspections (Valcarcel et al. 2003).

Kassa et al. (2001) described a numeric rating scale derived from matching the results of swabbing different surfaces (hand washing sinks faucets, freshly cleaned and sanitized food contact surfaces, coolroom and freezer door handles) with the results of visual inspection. Such ratings can be used to assess the effectiveness of staff training or articulate the need for food safety-related competencies (a detailed knowledge of the likely reservoirs of hazards; the nature, formulations and processing conditions in foods; and the factors that will enable an increase in the number/level of hazards) (Mayes 1994).

The results can also lead to the development of GMP (cleaning programs, hygienic practices and facility design) as well as cleaning/sanitation assessment criteria such as the acceptable level of contamination of food contact surfaces or the desirable reduction of bacterial populations after cleaning – a five decimal reduction within 30 seconds for Listeria (Chamber 1965), for example.

Future directions

Although the area of food safety represents the bulk of research on food service systems, some processing parameters still do not have theoretical justification. The notion of ‘playing safe’ often leads to the acceptance of over-conservative regimes such as the chilling time of 90 min recommended by New South Wales Health Department 1999c,d). In practice, cooked beef cooled to 7.5°C within 15 h did not support the outgrowth of C. perfringens (Juneja 1999). Furthermore, the need for six decimal reduction of C. botulinum during cooking (New South Wales Health Department 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d) can also be questioned – the high populations of this pathogen are extremely rare (Murall & Stewart 1998d).

In order to ‘strengthen’ the food safety design, the application of natural antimicrobials (spices, salt, sugar, organic acids, bacteriocins and lactate) in a synergistic combination of subtle preservation hurdles can be investigated. The effectiveness of protective cultures in traditional cook-chill foods against such pathogens as Salmonella and Listeria can be tested. In LSL processing, microencapsulation or the development of a release mechanism from the packaging material can protect the cultures from heat. Furthermore, the whole process of LSL meal production can be re-engineered – a hot-fill method can be replaced with aseptic packaging. This would facilitate the incorporation of protective cultures and other beneficial bacteria such as probiotics. The chilling of the product before pumping would prevent overcooking of the product during pumping, and cheap recyclable packaging can be used. The enrichment of meals with bacteria stimulates consumers’ immunity (Perdigon et al. 1999) and fits with the ‘better food safety through nutrition’ concept.

Further improvements in validity and accuracy of predictive models would reduce the need for challenge studies. In commercial practices, operators often innovate by modifying traditional and LSL cook-chill methods. Some upmarket food services use prime cuts of meat/fish, which are only sealed/browned on the day prior to consumption, the core temperature never reaches the requirements of the codes of practices. In some cases a product is ‘hygienically’ packaged without the pasteurization step. Companies supplying recyclable packaging are experimenting with LSL meals plated at a CPU. All these new processes should be validated.

It can be concluded that the knowledge of food safety should match the growing complexity of modern food service systems. Rough assumptions of parameters/limits are no longer satisfactory. Theoretically justifiable boundaries are needed in order to make informed choices. The fine-turning of processing parameters by means of predictive models and sophisticated preservation systems offers the potential for delivery of less processed meals, which are safer and have superior sensory and nutritional quality at the same time.

References


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