Food Microbiology and Safety Management Systems: Opportunities and Constraints

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Introduction

Fulfilling the expectation from the agricultural and food industry of an abundant and safe food supply is a complex process. It involves plant cultivation, animal husbandry and natural-resource management, including food manufacturing, distribution and retailing. These days raw materials are sourced globally, an increasing number of processing technologies are used, and consumers are spoilt for choice with the range of products available. The consumer also now expects food to be convenient, fresher and 'less processed'. Ensuring the production of safe and high quality food has necessitated the development of extensive food safety assurance systems that have to be implemented throughout the food supply chain.

The global population is now more than 7 billion and is expected to pass 9 billion before 2050. Producing the maximum amount of food from the available land in a sustainable manner will therefore become increasingly important (Figure 1).

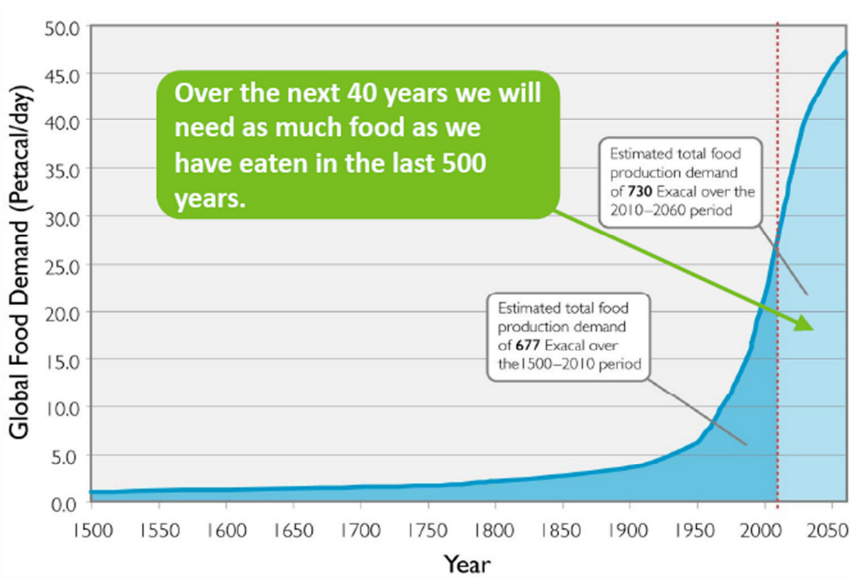

Figure 2: Mega shock: Food security (Gobius & Cole, 2012)

According to Food and Agriculture Organisation (FAO) findings the average adult needs 2300 calories a day to lead a healthy and active life. Sub-Saharan Africa was the only region where the average food supply was below the daily adult requirement. South Africa ranked 40th out of 105 countries in a Global Food Security Index which has the US in the top spot and the Democratic Republic of Congo at the bottom. Therefore the focus of food safety assurance also now includes avoiding losses by avoiding disruptions through food safety/biosecurity issues.

Microbiological processes have important roles in nearly all stages of food production. Therefore, food science professionals will be key players in making the improvements to food production that are required to feed the growing world population. Recently the Society for General Microbiology, the Society for Applied Microbiology, the British Mycological Society and the British Society for Plant Pathology released a mission statement that outlines nine research themes through which microbiologists can participate in food safety and security:

- Soil health and nutrient cycling
- Plant–microbe dynamics
- Crop pathogens
- Gut microbiology in farm animals
- Animal pathogens
- Food spoilage
- Food safety and human diseases

We have been exploiting the beneficial properties of micro organisms in the production of food for thousands of years. Early societies discovered that bacteria and fungi, through fermentation processes, could be used to maintain a safe, plentiful and long-lasting supply of foodstuffs such as cheese. Today we consume probiotics and expect that they will have beneficial physiological effects through specific microbial actions.

There is however also a dark side to food microbiology and microorganisms can have serious detrimental effects on food production. The spread and evolution of food pathogens is a growing problem for product yield and consumer safety. As exemplified by the recent outbreaks of *Escherichia coli* infection in Germany and *Listeria monocytogenes* infection in the United States, microbial food contamination remains a major problem. It is impossible to eliminate microbial contaminants from agricultural products and therefore these microorganisms play a role throughout the food processing chain. These food contaminants are of great social and economic importance.

Highlights in Food Microbiology History

If we look back at the history of food microbiology it is clear that microbiological research has delivered major advances in food security and safety. Some important milestones are:

- Identification and application of safe processes for food preservation, such as canning and pasteurization, and understanding the biology of pathogenic and spoilage microbes to reduce their transmission in the food chain, leading to developments of safer foods with a longer shelf life.

- Exploiting antimicrobial substances produced by naturally occurring microbes as weapons against plant and animal pathogens.
- Vaccine development to improve the health of livestock and reduce transmission of animal pathogens to humans.
- Producing novel food products, including probiotics and nutritionally enhanced food through fermentation.
- Exploiting microbial processes to manage or reduce waste.

In the 1930s, the concerns were mainly with food preservation and spoilage. Studying the natural ecology of food, spoilage organisms as well as inhibiting microorganisms by various food preservations, e.g. canning, low temperature, low water activity or low pH. In the 1940s foodborne disease was not very prominent and the only food pathogens that were well known were *Clostridium botulinum* and *Staphylococcus aureus* and *Salmonella* spp.

Other highlights are given in Table 1.

Table 1: Other highlights in food microbiology:

Early 1920s	-	12-D process for canned foods developed
Mid 1920s	-	Universal pasteurisation adopted and safe milk assured
1930s	-	Food preservation & spoilage
Before 1939	-	Widespread use of pure culture starters for fermented foods
1943-45	-	Salmonella recognised as problem in dried eggs
1959	-	Aflatoxins discovered – many others follow
Early 1960's	-	Salmonella contamination found in many dried foods
1960- 1969	-	Death – type E botulism
1965	-	Mandatory pasteurisation of liquid eggs
Late 1960s	-	Salmonella contamination found in many dried foods
1971	-	Unfamiliar agent *E. coli* O27:H20
1975-1985	-	New foodborne pathogens recognised *Y. enterocolitica, C jejuni, E. coli* 0157:H7*, V. cholerae, L. monocytogenes*
1980-1989	-	*C. jejuni* leading cause of gastroenteritis, other *Vibrio* spp. also identified

Food Safety Assurance

The Hazard Analysis and Critical Control Point (HACCP) system was already developed in the early 1960s in the USA in order to produce safe food for the space programme. In its original form the HACCP system consisted of three principles. Later, the concept was extended by ICMSF (1988) and

NACMCF (1989) to the seven principles which have meanwhile been incorporated into Codex Alimentarius (FAO/WHO Codex Alimentarius Commission, 1997). The HACCP system of Codex Alimentarius with its seven principles can be structured into three elements: hazard analysis (principle 1), measures for hazard control (principles 2-5), verification and documentation of the system (principles 6-7).

Traditionally food safety and quality was pursued with a reactive approach. Although these strategies historically proved relatively effective, their deficiencies in relation to microbial food safety have long been recognised. This recognition, and the successful adoption of innovative, proactive HACCP strategies to ensure the safety of food for astronauts in the 1970s, was however insufficient to overcome reliance on the flawed strategies of end product testing and 'snap shot' premises inspection in pursuit of safe food. Initially there was resistance in accepting the HACCP principle and this was to some extent attributable to the resistance of the scientific community to accept the system even though there was quite strong scientific evidence.

It is difficult to understand the persistence to retrospective protection strategies over such a long time given their obvious limitations. One possible explanation accumulating evidence was ignored was possibly because it was believed that good hygiene practices were adequate. Even though in various food sectors it had been shown that prevention of contamination alone was not sufficient in assuring safe food. The oldest evidence was from the dairy industry where all attempts to produce safe raw milk had consistently failed. In the pork industry too, convincing proof had been provided that, even very advanced systems of hygiene were insufficient to reduce the incidence of *Salmonella* spp. on carcases to an extent which would allow distribution of virtually pathogen free raw meat. Finally, transmission of enteric infections by soiled vegetables has long been known to occur and there remains clear evidence of the inadequacy of rinsing alone as a method of removing pathogens from a contaminated product, ingested without cooking.

In 1990 four principles were set out which were presented as fundamental to providing safe food for the consumer:

- More rapid adoption of HACCP strategies throughout the entire food chain
- Implementation of safety assurance measures should become the obligation of the producer at every stage in the industry , subject to verification throughout
- With a transfer of responsibility to the industry, the role of government agencies would contract to one of responsible verification

- The consumer would take responsibility too, by seeking relevant information to ensure that the protections and safety measures introduced during production were not negated by their own actions

Facing the changing context in which food is produced and traded, important changes in food safety policies and food regulatory measures have taken place at both international and national levels. The Sanitary and Phytosanitary (SPS) Agreement of the World Trade Organization (WTO) put emphasis on the role of the Codex Alimentarius Commission (the “Codex”) as representing the international consensus with respect to food standards. Codex is an inter-governmental programme for standards setting, with the objective of promoting food safety and fair practice in trade.

Moreover, the SPS Agreement has established the tenet that “Members shall ensure that their sanitary and phytosanitary measures are based on an assessment, as appropriate to the circumstances, of the risk to human, animal or plant life or health”. This has led to the progressive emergence of a risk-based approach to food safety. It has fostered the development of formal methodologies for risk assessment, whereby risk analysis has now become a core paradigm in modern food safety governance.

Microbiological Food Safety Programmes

In order to control the outbreaks of foodborne illnesses many countries regulated HACCP and subsequently the food industry implemented Food Safety Management Systems (FSMS). An FSMS can be defined as a company specific system of control and assurance activities in order to realise and guarantee food safety (Figure 2). A FSMS implements activities that control the product and process conditions and keep them within acceptable limits. It also includes assurance activities which evaluates the systems performance and which facilitates any necessary changes. Introduction of a HACCP based system eliminates the fluctuations in microbiological quality and safety intrinsic in uncontrolled practices (Figure 3). Several private Quality Assurance (QA) standards are available, like ISO 22000 (ISO, 2005b), International Food Standard (IFS, 2007), Global Standard for food safety (BRC, 2008) and many others. These standards have been developed for the food processing industries and once implemented it is possible for a company to attain certification. Certification is mostly demanded by retailers.

One of the biggest challenges a food processor has, is to implement these requirements in a company specific FSMS in order to assure food safety. A company specific FSMS should be the implementation of Good Hygienic Practices (GHP), Hazard Analysis Critical Control Point system (HACCP), management policies, traceability and recall systems into a company specific system. Quite a large constraint currently is that the performance of FSMS in practice is, however, still variable. Attention is shifting from implementing QA standards to the better understanding of the performance of an FSMS. As a consequence, various audit tools have been developed to determine the performance towards QA standards but they basically check on compliance to the set requirements, for instance, during internal or external auditing.

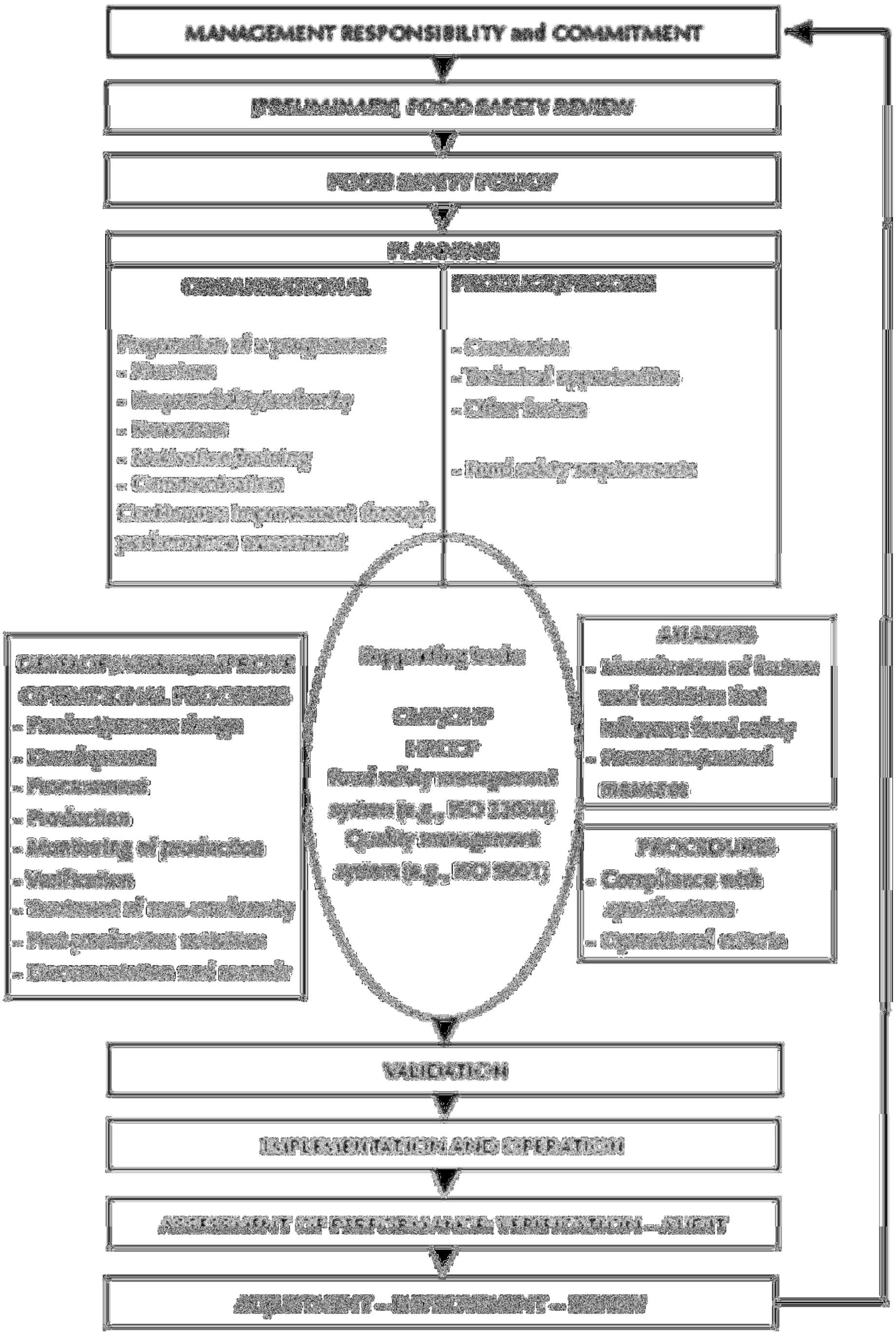

Figure 2: Development of a Microbiological Food Safety Programme

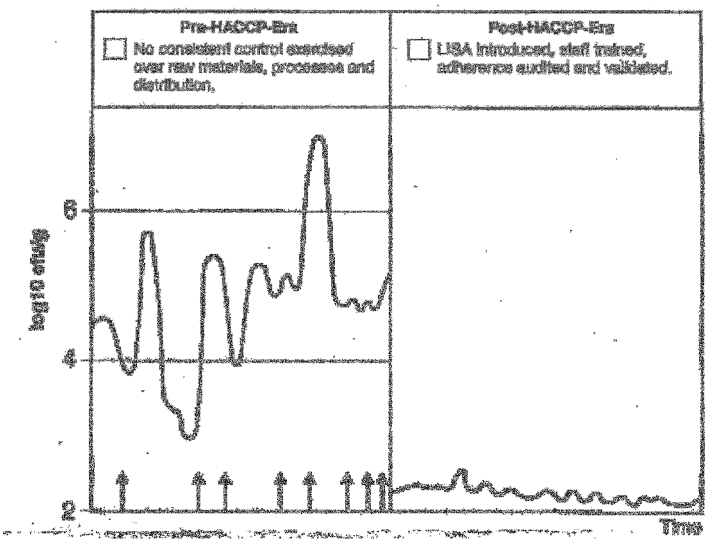

Figure 3: Effect of implementation of a longitudinally integrated safety assurance system

From my own experience in the South African food industry I have witnessed that there is great emphasis on the implementation of food safety standards. Typically one could find a range of these implemented in a single processing factory, i.e. BRC and SANS 10330, as required by different retailers. Many companies have certified systems. As indicated internationally the focus has been on the system side of the FSMS and there is generally a lack of focus on the underlying scientific food microbiology principles, both with implementation and during auditing. This is of great concern, as HACCP, which forms the core of these standards, is a system based on sound science and this reflects on the concerns by scientists when HACCP was first put forward as a proactive food safety assurance system. My experience in the industry has led me to have concerns on the current understanding of the basic principles of food microbiology and safety and has also indicated a need for further education to dicuss the latest food safety issues and scientific developments.

FSMS and Continuing Food Borne Outbreaks: a paradox

Microbes can enter the food chain at different steps, are highly versatile and can adapt to the environment allowing survival, growth and production of toxic compounds. Therefore despite great awareness of food safety internationally, the progress in medicine, food science and the technology of food production and development of FSMS, large food safety outbreaks in which micro-organisms play a prominent role, continue.

Estimates of the incidence of foodborne illnesses vary greatly, due mainly to large differences in the sources of data and in surveillance systems. Nevertheless, there is agreement that foodborne illness is one of the principal causes of human morbidity. In industrialised countries, the percentage of people suffering from foodborne diseases each year has been estimated to be up to 30%. The most common pathogens responsible for foodborne gastroenteritis are pathogenic *E. coli, Norovirus, Campylobacter* and non-typhoidal *Salmonella*. Only a small proportion of food borne illnesses are ever reported.

The rate of new diseases identified is increasing. The cause of disease is unknown for 80% of foodborne illnesses and 64% of patients die. In 1978 a new disease was identified every 10-15 years, in 1988 every 8-9 years and today a new disease is identified every 14-16 months.

Food Microbiology and Safety in a Changing World

Developments that may influence food safety in the future occur on different scales, from global to molecular, and in different time frames, from decades to less than a minute.

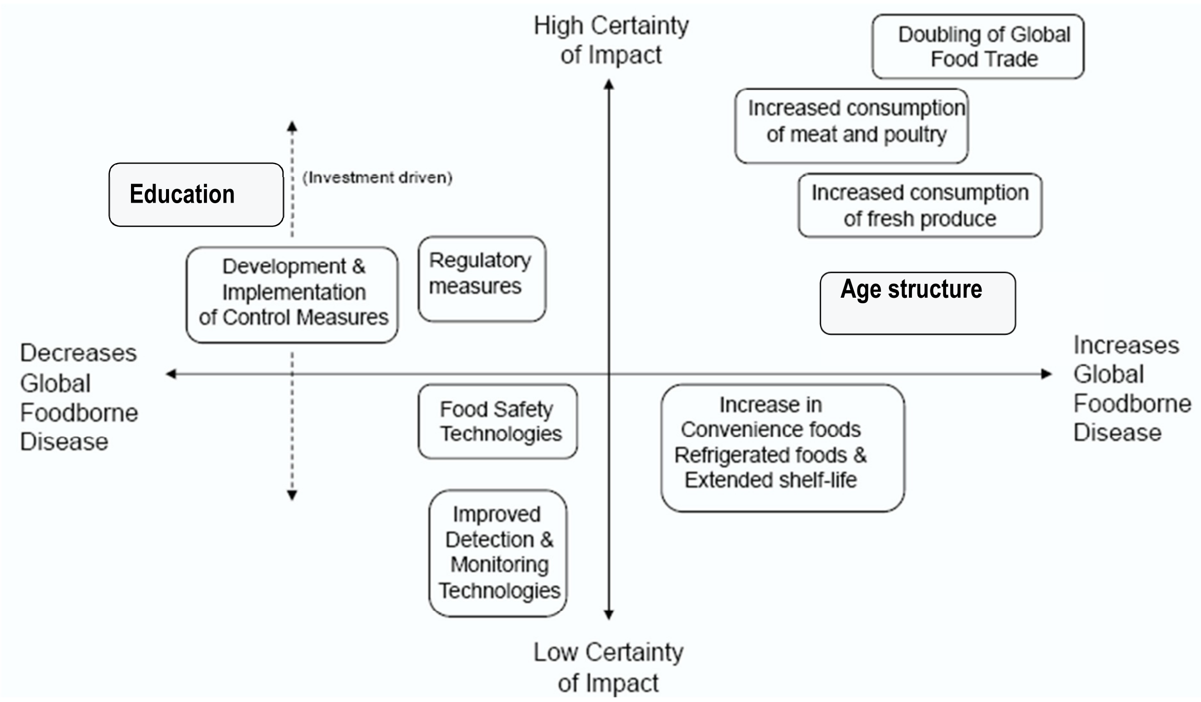

Figure 4: Trends in technology, trade and consumption likely to impact on microbial food safety

Some of the most important factors driving an increase in the burden of food-borne disease:

- doubling of the global demand for food and of the international trade in food
- significantly increased consumption of certain high-value food commodities such as meat and poultry and fresh produce
- reduced geographical barriers to spread of new variants
- less important factor would be the increased demand for convenience foods

Factors that may contribute to a reduction in the food-borne disease burden:

- ability of governments around the world to take effective regulatory measures
- development and use of new food safety technologies
- development of detection methods may increase the observed risk by the discovery of new pathogens or variants but will ultimately contribute to reduction

The most important factor in reducing the burden of food-borne disease:

- our ability to first detect and investigate a food safety issue and then to develop effective control measures

Climate change

Climate change is considered to be one of the greatest current challenges to mankind, affecting all sectors of society, including nutrition, food security and food safety. All foodborne pathogens and their associated diseases are potentially affected by climate change. A time series analyses in several European countries indicated that salmonellosis increased by 5-10% as the weekly temperature increased by 1°C. Quite interesting is that compared with infections caused by *Salmonella* Typhimurium infection with *Salmonella* Enteritidis appears to be more sensitive to the effects of environmental temperature. If one looks at campylobacteriosis, the role of climate related parameters such as short-term increases in temperature on human is unclear. For this pathogen the effect seemed to be confined to temperatures between about 5 and 10–15°C. Other bacterial agents of foodborne disease may also be impacted by global climate change. The fact that many, if not most foodborne bacterial pathogens can grow at room temperature with faster growth favoured at elevated temperatures means that increases in ambient temperatures may also speed up the rate of pathogen proliferation from production to consumption, all other factors remaining unchanged.

Antimicrobial resistance

Antimicrobial agents are used widely both in agriculture and for human health; this unfortunately has contributed to the emergence of resistant microbes. Resistance is becoming a growing concern for human health care, i.e. methicillin- resistant *Staphylococcus aureus* (MRSA). Micro-organisms have an immense diversity and can easily transfer genetic information, making the emergence of new hazards, and adaptation to previously effective intervention methods possible. At present, it is not clear what proportion of resistance encountered in human pathogens originates from selection in and transfer from animal reservoirs.

Molecular methods for complex food analysis

Elucidating the molecular mechanistic processes that underlie the observed physiological behaviour of pathogens in food has always been a challenge in food microbiology. This is dependent on proper identification of:

- the micro-organisms in the food and
- the food components that are relevant in determining the microbial stability of such foods

The latter range from small molecules, flavour-like molecules, food preservatives and other organic molecular to the macro-ingredients i.e. proteins (peptides), carbohydrates and fats. The problem is that the microbes are not uniformly dispersed throughout the product, i.e. for many ready-to-eat products and equally so for liquid products. Analysis of micro-organisms in foods may be either a direct assessment related to production processes or inspection or research-oriented in which physiological deductions are made from molecular data. Currently they are generally based on DNA-detection systems, either specific for ribosomal genes or in the more advanced systems for specific sequences that occur along the entire genome. Thus, in the case of relevant, closely related bacterial isolates it is increasingly easy to identify unique sequences. This increases the ability to identify new pathogens or variants and my lead to an increase of observed risk. This also leads to the amendments of regulations as seen with the USA's latest call for non O157 *E. coli* serotypes to be classified as adulterants during meat processing. The FSIS declared O157:H7 an adulterant in 1994. During 2012 Shiga-toxin producing *E. coli (*STEC) serotypes O26, O45, O103, O111, O121 and O145 were added.

Interaction between micro-organisms and their environment

Stress adaptation of micro-organisms in foods or upon being exposed to food processing conditions that may lead to the induction of survival systems and could even induce virulence in pathogens. Successful activation of stress response systems by some but not all strains may be instrumental in letting some strains adapt to the 'adverse' conditions in the food chain. These days we study the response to high temperature stress conditions at the molecular level. Various strains of bacilli, produce spores resistant to temperatures up to and well above those of 140 °C. Spores express specific stress response genes during germination, some of which are likely responsible for repair of incurred thermal damage. Environmental stress and food preservation methods, e.g. heating, chilling, acidity, and alkalinity, induce adaptive responses within the bacterial cell. Microorganisms that survive a given stress often gain resistance to that stress or other stresses via cross-protection.

The microbial response to stress induces various degrees of injury depending on the physiological state of individual cells within the population, presenting viable-but-nonculturable cells. Severely injured, yet metabolically active, cells of foodborne pathogens such as *Salmonella, E. coli, Shigella,* and *Campylobacter* that cannot be resuscitated under routine laboratory conditions can enter a viable-but-nonculturable state and maintain their pathogenicity. Under appropriate intrinsic (e.g., nutrients, a,) and extrinsic (e.g.. temperature, relative humidity) conditions, many injured cells will repair and regain the characteristics of normal cells at any point from preharvest to consumption and exhibit increased stress tolerance as a result of stress adaptation. We often see the repair process as a delay in germination of spores, a prolonged lag phase for cells and the inability to multiply until fully repaired.

Bacteria respond to stress by altering their cellular morphology, membrane composition, cellular metabolism, and degree of virulence. These bacteria that have been subjected to sub-lethal stresses frequently show cross-protection against other stresses. This is caused by:

- sublethal treatments that were insufficient to cause death or
- an innate means of protection from destructive conditions or treatments

The hypothesis is that " bacterial cells could adapt or acquire resistance to different conditions by modifying metabolic activities, adjusting nutrient utilization, or by using enzymes that were previously present in a recessive role".

The presence of injured cells in a food can pose major public health concerns, since many bacterial pathogens can become more resistant to heating and other commonly used microbial reduction strategies as result of sub-lethal injury. It is possible for the injured cells to repair in a food matrix and restore virulence. This requires a complex series of biochemical events that will differ based on the food product as well as the type and degree of injury. However, many injured pathogens either retain or exhibit enhanced virulence in foods, thus making their detection crucial to safeguard the food supply.

Bacterial stress and virulence

Injured cells may initially go undetected during routine quality control checks and at critical control points during manufacturing. However, subsequent cellular repair in the food may allow for growth in particular during extended shelf life. For instance *E. coli* 0157:H7 has 3 virulence factors, verotoxins 1 and 2 and the attaching and effacing gene, eae. It has been shown that these are retained after heat stress, these virulence genes seem to be part of an adaptive response to stresses encountered. Pathogenic microorganisms may see exposure to stress in both natural environments and food processing facilities as a signal for the expression of virulence factors. Temperature-regulated virulence factors have been identified in enteroinvasive *E. coli*, *Y. enrerocolitica* and heat shock has been linked to virulence in *L. monocytogenes* , *Salmonella typhimurium* and *Shigella* spp. Acid tolerance of *E. coli* 0157:H7 likely contributes to its low infective dose.

Opportunities

The goal of the Integrated Food Security Strategy (IFSS) of the South African Government is to eradicate malnutrition, food insecurity and hunger in South Africa by 2015. This presents an enormous challenge and opportunity for food science professionals. During 2012 the IFT indicted that the areas of food safety and nutrition were the two areas of food science world-wide where there is a growing need for expertise. It is evident from what has been presented that food science professionals will have to change the way that they approach a career in food safety.

- The importance of food safety issues on livelihoods and consumer health needs to be higher on the political agenda of countries in sub-Saharan Africa.
- Food safety management systems in sub-Saharan Africa need to be able to respond to both global and domestic challenges
- There is a need to identify food safety hazards of main concern to consumer health and livelihoods and where they occur on the food chain.
- There is a need to quantify potential economic benefits resulting from improvements in food safety and consumer health.
- Appropriate food safety legislation needs to be introduced in consultation with all players in the food production, processing, processing and catering sectors.
- There is a need for national food safety control systems which can be supported by appropriate food laws, enforcement and support (for example accredited laboratories).
- Consumers, food handlers and processors need to be educated in food safety issues. Food inspectors need appropriate training so that they can contribute effectively.
- It is necessary to form and/or strengthen consumers' associations and integrate them at both local and international levels
- There is need to develop appropriate evaluation procedures for food safety hazards through provision of accredited analytical laboratories.
- There is a lack of information concerning the availability and suitability of lower cost, safer local alternatives for use by poor people and whether consumers are willing to pay more for safe food and if this can be used as an incentive for producers and processors to produce safer foods.

The current and future challenges that have been mentioned related to food microbiology and safety will require a fresh attitudes and knowledge supported by new education and training strategies. This also presents a challenge to those of us educating food science professionals. The challenges mentioned and consequence will place great responsibility on the food manufacturers and food service providers to ensure the safety and quality of their products. This will increase in demand food science professionals that are well educated and these skills academically acquired skills will have to be maintained.

Strategy for the department

The Department has shown excellent growth. Despite our success we need to set new goals, because the areas of food science and nutrition are constantly offering new opportunities which we have to be a part of. Therefore, it is essential that we are constantly adapting and proposing new initiatives. My vision is that the Department of Food Science will be the academic leader in our respective research areas dissemination of food science and nutrition knowledge to educate students, promote optimal health and well-being and food security to serve the needs of South Africans and beyond.

Therefore our strategy must be to make sure

- That our students who will be the future leaders in research, industry, academic and government are well-prepared through visionary undergraduate programs with academic excellence as priority
- That our research programs focus on cutting edge research result in the discovery of new knowledge innovative technologies we form strategic alliances to advance food security and promote health and well being
- That we contribute to community development in areas where we can make a difference to improve:
    - Food safety and quality of food produced by the South African industry, Government policies, Food security and well-being of consumers

More specifically:

Strategic collaboration

•We need to identify strategic researchers we can collaborate with e.g. collaborating with researchers who are highly cited

Research

•Improve the quality of our research. However that is also dependent on the quality of our post-graduate students.

- •Write review articles jointly for the top journals e.g. Trends in Food Science and Technology etc. (e.g. Topic of Nutricereals or Nutrigrains for Trends in Food Science and Technology)
- •Attract the best post-docs and PhD students. Increase our post-doc numbers, e.g. get our own PhD students to do an additional year
- •Grow academic staff numbers
- •Identify top honours students who can be good post-graduate students and try and retain them, provide them with good bursaries
- •Promote other research areas in the department that are not promoted enough e.g. Sensory, Nanotechnology, Food microbiology and safety
- Aligning ourselves with organized agriculture and organized industry

Teaching and learning

- •Innovative ways of teaching
- •Use of multi-media, now what the latest trends and technologies in multi-media are that can be used for teaching

The research in our department is focusing increasingly on the interface between food science, nutrition and health. Recent initiatives will enhance growth in this area these are essential for us to remain relevant & impact in these areas.

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