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Food safety in the human food chain

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4 Safety in the food industry: processing

AC Baird-Parker & GW Gould

INTRODUCTION

With few exceptions, all foods, following harvest, slaughter or manufacture, lose quality at some rate or other in a manner that is dependent on food type, composition, formulation, packaging and storage conditions. The potential for quality loss may occur at any of the many stages between the acquisition of raw materials and the eventual consumption of a finished product and quality loss may therefore be accelerated, or minimised, at any of these stages.

The total preservation of a food is therefore often highly multicomponent in that it seldom relies on one factor alone. Nevertheless, the principal quality loss reactions, that are consequently also the principal targets for effective preservation and control, are well known, and they are relatively few. They are listed in Table 1, and include some that are essentially physical, some that are chemical, some that are enzymic and some that are microbiological. When preservation fails and these various reactions or activities accelerate or escape control, the consequences range broadly. At the one extreme the consequences may be relatively trivial, though undesirable, such as loss of colour, flavour or texture change within foods. At the other extreme, the most serious forms of quality loss are those associated with the presence or multiplication of micro-organisms. And again these range from undesirable reactions causing spoilage, that may nevertheless result in economically-important losses of foods if not controlled, to the transmission of the life-threatening diseases that are caused by the most hazardous of the food-poisoning micro-organisms (Table 2).

Whilst most preservation techniques therefore aim to control all the forms

Table 1
Major reactions leading to quality deterioration of foods

Reaction	Example		Consequence
Physical change	Movement of moisture	(i)	Drying-toughening of texture
		(ii)	Hydration-softening of texture; loss of crispness; sogginess
		(iii)	'Lumping' and aggregation of particulate foods
Chemical change	Oxidation	(i)	Oxidative rancidity
		(ii)	Colour change
	Maillard reactions	(i)	Brown discolouration
		(ii)	Texture change
Enzymic activity	Polyphenol oxidase	(i)	Enzymic browning
	Lipoxygenase	(i)	Rancidity
	Lipase	(i)	Lipolytic rancidity
	Protease	(i)	Texture change
		(ii)	Gelation
		(iii)	Flavour change
	Amylase	(i)	Texture change
Microbial activity	Growth of spoilage organisms	(i)	Food spoilage
	Growth of toxigenic organisms	(i)	Food poisoning-intoxication
	Presence of infective organisms	(i)	Food poisoning-infection

Table 2
Microbiological quality deterioration of foods

Food poisoning

(i) Presence or multiplication of infective micro-organisms eg *Salmonella* spp. and *Listeria monocytogenes*

(ii) Multiplication of toxigenic micro-organisms eg *Staphyloccoccus aureus* and *Clostridium botulinum*

Food spoilage

(i) Minor products
eg Thiols, esters, amines and peroxides causing off odours, flavours, discolouration etc.

(ii) Major products
eg Lactic acid, acetic acid, H_2 and CO_2, causing souring, blowing etc.

(iii) Enzymes
eg Proteases, lipases and amylases causing textural and flavour changes etc.

(iv) Biomass
eg Growth of *Pseudomonas* sufficient to cause visible slime on meat; yeast haze in drinks, pickles; mould colonies on dough-based products and jams.

Source: Adapted from Gould (1989a)

of quality loss that may occur, the overriding priority is always to minimise the occurrence and growth of micro-organisms, and the types that cause food-poisoning in particular. This is achieved first by selecting and using the optimal processing and preservation techniques for a particular foodstuff, and then by instituting monitoring and control measures to ensure that these techniques are correctly used.

PROCESSING AND PRESERVATION

Basis of food preservation

Preservation is all about applying procedures that inhibit or destroy micro-organisms or restrict their access to foods. It must therefore operate through those factors that most effectively influence the growth and survival of micro-organisms. Such factors are not numerous. They include a number of essentially physical factors, some predominantly chemical ones and some microbial ones which depend on the nature of the micro-organisms that may be present. The factors have been classified in a number of ways, but the most widely quoted classifications (Mossel & Ingram, 1955; Mossel, 1983) separate the major factors into those which are:-

(i) *Intrinsic factors*, which include those chemical and physical factors that are *within* the food, and with which a contaminating micro-organism is therefore inextricably in contact;

(ii) *Processing factors*, which, as the name implies, are deliberately *applied* to foods in order to achieve improved preservation;

(iii) *Extrinsic factors*, which include those factors that influence micro-organisms in foods, but which are applied from *outside* the food and act during storage;

(iv) *Implicit factors*, which include those factors that are related to the *nature of the micro-organisms* themselves, and to the interactions between them and with the environment with which they are in contact during growth;

(v) *Net effects*, which take into account the fact that many of the factors strongly influence the effects of each other, so that the overall effect of *combinations* of factors may not be readily predictable, but may be greater than the perceived effects of the single factors would lead one to expect.

Major processing and preservation techniques

The major techniques that are employed are therefore all based on a relatively limited set of factors, so that the range of techniques is necessarily limited also. They are summarised in Table 3 (Gould 1989a) in such a way as to highlight the fact that most of the techniques act through the slowing down or, in some instances, the complete inhibition of microbial growth.

Table 3
Major antimicrobial preservation technologies

Aim	Factor	Mode of Achievement
Slowing or inhibition of growth of micro-organisms	Low temperature	(i) Chill storage (ii) Freezing
	Reduction in water activity	(i) Drying (ii) Curing-addition of salts (iii) Conserving-addition of sugars (iv) Addition of other solutes
	Restriction of availability of nutrients	(i) Water-in-oil emulsions
	Decrease in oxygen level	(i) Vacuum-packaging (ii) Nitrogen-packaging
	Increase in carbon dioxide level	(i) 'Controlled atmosphere' bulk storage (ii) 'Modified atmosphere' product packaging
	Acidification	(i) Reduction of pH-value by addition of acids (ii) Lactic fermentation (iii) Acetic fermentation
	Increase in ethanol level	(i) Alcoholic fermentation (ii) Fortification
	Use of preservatives	(i) Addition of inorganic preservatives (eg sulphite, nitrite) (ii) Organic preservatives (eg propionate, sorbate, benzoate, parabens) (iii) Antibiotics (eg nisin, primaricin (natamycin))
Inactivation of micro-organisms	Heat	(i) Pasteurisation (ii) Sterilization
	Ionizing radiation	(i) Radurization (ii) Radicidation (iii) Radappertization
Restriction of access of micro-organisms to products	Packaging	(i) Plastics (ii) Foil laminates (iii) Cans
	Decontamination	(i) Ingredients (eg by gases or irradiation) (ii) Packaging materials (eg by chemicals (H_2O_2), heat or irradiation (UV, V or X)
	Aseptic processing	(i) Aseptic thermal processing and packaging without contamination

Source: Adapted from Gould, Brown and Fletcher (1983).

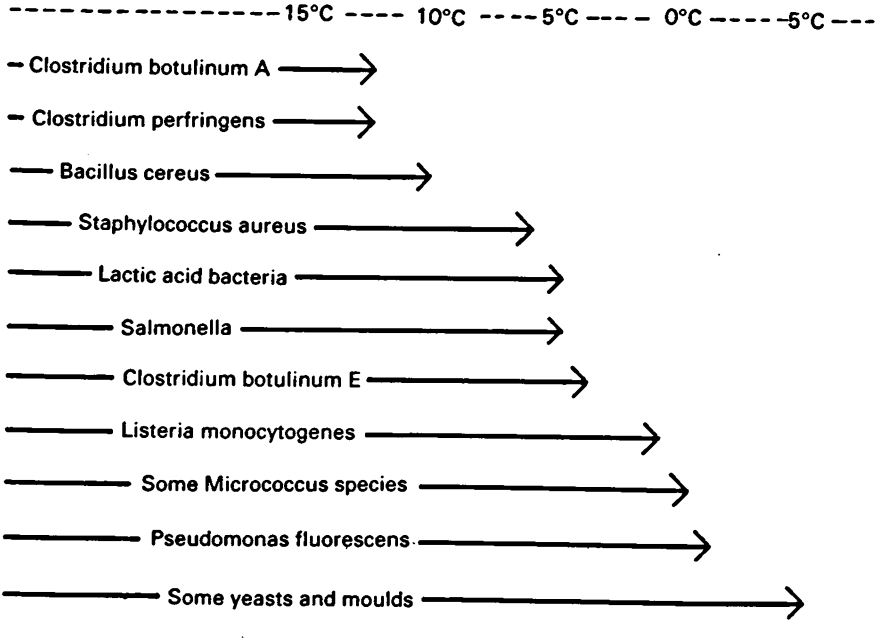
Few act by direct inactivation of the target bacteria, yeasts or moulds. Then, in addition to the main inhibiting and inactivating techniques, there are the, mostly newer, procedures that restrict the access of micro-organisms to the food product. The most important of these techniques, and their influences on the most serious forms of quality loss of foods, are summarised below.

Low temperature

As the temperature of chill-stored foods is reduced the numbers and types of micro-organisms that are able to multiply are reduced also (Figure 1). Particularly important temperatures are those around 12°C, which represents the lower limit for growth of *Clostridium perfringens* and for the proteolytic strains of *C. botulinum*, and about 3.5°C which is the lower limit for some of the non-proteolytic strains of *C. botulinum*. Until recently this would have been the chill-storage temperature below which no food poisoning organisms of concern would have been expected to multiply. However, outbreaks attributable to *Listeria monocytogenes* have been increasingly recognised, and this organism can certainly grow at temperatures below 1°C.

At temperatures below zero many types of spoilage micro-organism may

Figure 1
Low temperature limits for microbial growth

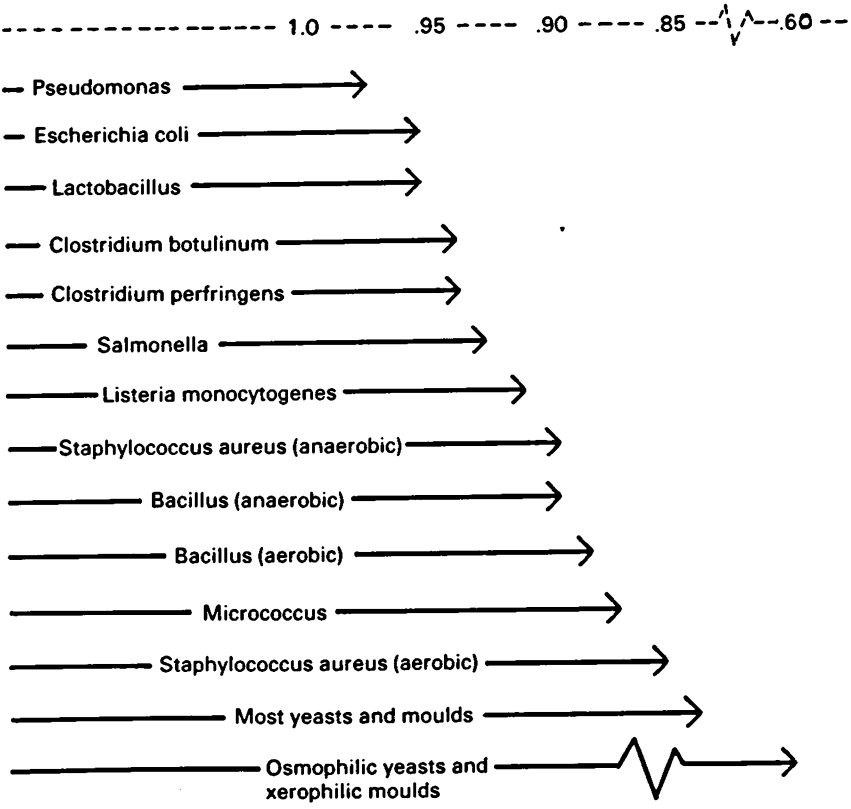


still grow, though very slowly, down to about −7°C or, occasionally reported, −10°C, so that badly-stored frozen foods may slowly spoil through the activities of micro-organisms if allowed to rise in temperature to this extent, even if thawing has not occurred. However, no micro-organism is capable of growth below about −10°C so that, at the temperature of properly-stored frozen foods, nominally −18°C in many countries, microbial growth is completely prevented.

Reduction in water activity

Water activity (a_w) values [for definition see glossary] are widely used to predict the stability of foods with respect to the potential for growth of micro-organisms and also the chemical, enzymic and physical changes that lead to loss of quality. Figure 2 lists some of the important low a_w limits for

Figure 2
Low water activity limits for microbial growth



growth of key food-poisoning and spoilage micro-organisms. Of the food-poisoning bacteria, *Staphylococcus aureus* is the most tolerant, being capable of multiplication at a_w values as low as 0.86 if oxygen is present, though only down to about 0.91 if it is absent as in a vacuum-packed product.

At a_w values below this, the predominant spoilage organisms are yeasts and moulds, some of which may grow, though very slowly, at water activities just above 0.6. Dried foods are therefore formulated and stored so as to maintain an a_w value well below this, commonly near to 0.3, where the other chemical, enzymic and physical changes that can affect quality are minimal.

Vacuum and modified atmosphere packing

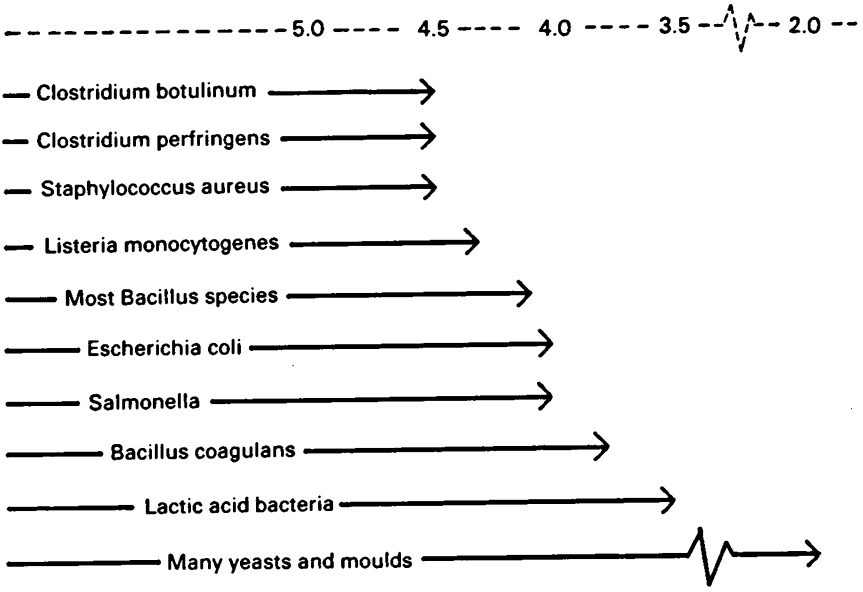
There has been a rapid expansion of vacuum and modified atmosphere packaging of foodstuffs during the last decade. The effectiveness of the technique firstly derives from the removal of oxygen, eg in vacuum or nitrogen-flushed packs, and the consequent inhibition of growth of micro-organisms that require oxidative metabolism in order to grow. Of course, fermentative organisms may continue to multiply, but they do so only slowly and generally with less unpleasant effects on the quality of foods. For example, chill-stored gas- or vacuum-packed raw meat deteriorates through slow growth of lactic acid bacteria and related micro-organisms in a manner that many consumers do not find objectionable. In contrast, in air, oxidative bacteria produce slime and, eventually, amines and other unpleasant-smelling metabolites. Secondly, the increasingly used carbon dioxide in modified atmosphere packs has the additional advantage of not simply replacing oxygen, but of having a specific antimicrobial effect of its own, and so extends safe high quality shelf life further.

Acidification

Figure 3 lists the absolute pH-limits for the growth of the most important food-poisoning micro-organisms, and some that cause food spoilage. The Figure illustrates the critical nature of the pH value of 4.5, which represents the pH below which *Clostridium botulinum* is widely regarded not to grow in foods. Consequently, it is not necessary to heat foods that are more acid than this to the same extent as higher pH 'low acid foods'. Below about pH 4.2, other food-poisoning organisms are well-controlled and the major problems, in unheated foods, are the acid tolerant bacteria, such as lactic acid bacteria, and the yeasts and moulds, many of which can grow at pH values well below 3.

Figure 3 however omits a further important fact. This is that the nature of the acid that is present greatly influences preservation. In fact, most of the effective and widely-used preservatives are acids, such as the weak lipophilic organic acids like sorbate, benzoate and propionate, or the

Figure 3
Low pH limits for microbial growth



inorganic ones like sulphite or nitrite, and *all* of these are most effective at low rather than at high pH values. Indeed, with the possible exception of the parabens for some applications, there are still no wide-spectrum anti-microbial preservatives that are highly active at near-neutral pH values.

Heat and irradiation

Unlike the preservation techniques summarised above which essentially act by inhibiting microbial growth, heat and, to a still minimal extent, ionising radiation are employed to inactivate micro-organisms. The aim of thermal processing is to deliver sufficient heat to a food to reduce the chance of survival of an organism that is of concern, or is capable of growth in that food, to an acceptably low level. The rationale for deciding what is an acceptably low level has developed over many years following the initial studies of Esty and Meyer (1922) on the thermal inactivation kinetics of spores of *Clostridium botulinum* type A, and the practical application of heat in the thermal processing industry is still derived from these early studies. Esty and Meyer aimed to set standards for sterilisation that would achieve a reduction in the spore population by a factor of 10^{11}- or 10^{12}-fold, and Hicks (1961) argued that the destruction of spores of *C. botulinum* by this extent was necessary to ensure the satisfactory safety of thermally processed

low-acid foods. These were the principal publications that initiated the now widely quoted '12 D concept'.

Likewise, a similar rationale forms the basis of effective pasteurisation process, but with different target micro-organisms, so that, analogously, concepts such as '7 D' (ie a thermal process that will reduce numbers by a factor of 10^7) have been suggested, for instance to ensure satisfactory safety with respect to the inactivation of *Salmonella* during the cooking of meat (Angelotti, 1978).

PREDICTIVE MODELLING OF MICROBIAL GROWTH AND SURVIVAL IN FOODS

Figures 1, 2 and 3 are misleading in the sense that they indicate relatively sharp cut-off temperatures, water activities or pH-values for growth whereas, in fact, growth of any particular micro-organism slows down more and more as the respective minima are approached. Furthermore, the processing and preservation techniques interact in such a way that used in *combination* their effects are often far greater than one would expect. These complex interrelationships of factors on the growth rates and inactivation rates of micro-organisms are being extensively studied now and mathematically modelled so that computer-aided predictions can be made of the likely level of growth or survival to be expected for a particular micro-organism during any combination of processing, storage and distribution regimes (Baird-Parker and Kilsby, 1987).

In the UK, for example, MAFF is funding a nationally coordinated programme of research into the growth and survival of micro-organisms in real food systems (Gould 1989b). The aim is to build on the new modelling expertise that is becoming available and to generate a computerised Predictive Microbiological Data Base that will be ahead of any similar development in the world. The Data Base will be held by the Campden Food and Drink Research Association.

The coordinated research programme is being carried out by micro-biologists, mathematicians and computer experts in the AFRC Institute of Food Research Laboratories, the Campden Food and Drink Research Association, the Leatherhead Food Research Association and the Flour Milling and Baking Research Association, along with Unilever Research and with small additional elements in the University of Bath and the University College of Wales at Cardiff. UK food industries are being invited to become involved in order to influence the selection of important target foods, special situations regarding manufacture, distribution, point-of-sale, in-home use etc and micro-organisms of special concern. In some instances, industrial partners will contribute experimental data to the developing system.

Output from the Data Base will be available, with professional

interpretation when necessary, to food companies and other interested parties.

Predictive modelling of microbial growth and survival is applicable to all types of micro-organisms, including bacteria, yeasts and moulds, and also to some extent to parasites and viruses. However, the project is concentrating at first solely on those food-related micro-organisms that are of major public health significance, with most effort directed initially to *Salmonella typhimurium, S. enteritidis* and other *Salmonella* species, to *Listeria monocytogenes*, to *Clostridium* species and to the *Bacillus* species.

The Data Base will be applicable wherever the growth, inactivation or survival of micro-organisms is of concern. It will enable resources to be concentrated more efficiently in the most critical areas, and so help to avoid or eliminate problems without recourse to expensive and time-consuming experimentation. In particular, with respect to processing, it will allow forecasting of the possibility and extent of multiplication or survival of particular micro-organisms during each stage of a process. In this way it will greatly improve the effectiveness of quality assurance procedures by providing a firmer base of information for decision making and for the identification of *critical points* in production systems, as well as in distribution, retailing and handling in the home.

Microbiological problems may arise when the desired effect is not achieved. This is usually due to errors in handling or processing procedures. The detection of such errors, their rapid correction and future prevention are major objectives of any microbiological control system (ICMSF, 1988). The modern approach to the control of microbial hazards, that provides the framework for effective implementation is the Hazard Analysis Critical Control Point concept (HACCP).

APPLICATION OF HACCP SYSTEMS TO ENSURE MICROBIOLOGICAL SAFETY OF FOODS

HACCP

The HACCP system is an essential component of all quality assurance programmes in which the basic philosophy is *prevention* of defects through the design-in of control requirements into product formulations, processing parameters and operating practices. HACCP augments and refines codes of Good Manufacturing Practices in that it concentrates effort and priorities for control on those requirements that are essential for safety. Most current Codes of Practice tend to be general and subjective, to cover both essential and non-essential procedures and practices for control and to give little guidance to the user as to the relative importance of these to the overall safety of the product.

Application of HACCP shifts emphasis for control from traditional end-

product testing and inspection, to control based on assurance of the quality of raw materials and effective control of all key operations by design, rather than retrospective testing for the presence of defective products. In essence, this takes control out of the laboratory into the manufacturing environment and better uses the total resources of the factory to assure that manufacturing procedures are properly applied.

Operation of HACCP

The system can be divided into four closely linked stages (Figure 4).

Figure 4
Steps in applying HACCP

(i) Identify hazards and understand risks
- microbes/toxins
- ranking (severity and frequency)

(ii) Identify Critical Control Points
- places where control must be assured

(iii) Select control and monitoring options
- effectiveness (utility, reliability, accuracy)

(iv) Exercise control
- implement QA procedures

Source: Baird-Parker and Mayes (1989).

Identification and assessment of the severity of hazards and risks

Microbiological hazards and risks are those associated with growing, harvesting, processing/manufacturing, distribution, sale, preparation and/or use of a raw material or product. Thus a hazard analysis will cover practices from the farm to the kitchen, and not only those activities under the direct control of the food manufacturer as these can have a strong effect on the procedures applied during processing to control product hazards to an acceptable level.

Hazards encompass unacceptable growth, survival or contamination by micro-organisms, or their metabolic products, causing illness or spoilage. Risk means the probability of occurrences of a hazard.

Determination of critical control points required to control an identified hazard

A Critical Control Point (CCP) can be defined as a location, practice, procedure or stage in the food production, distribution and use chain which can be used to control the risk (probability of occurrence) of an identified

hazard to an acceptable, ie safe level. CCPs relate solely to hazards that have been identified as results of hazard analysis of a particular operation and may include equipment, facilities or operating practices. For example a CCP could be harvesting of a raw material or product, the design or operation of a production environment or a particular piece of equipment, the manual handling of a food or operation of an automated filler, or a distribution system or procedure used in the home or a catering establishment for preparation of a food for consumption.

Specification of control and monitoring procedures
At each CCP, criteria for control (limits and tolerances) are specified, and documented, together with methods for monitoring that control is achieved. A procedure for action to be taken if an out of control situation is identified should also be agreed and documented. Criteria for monitoring may be of a physical nature eg measurement of a temperature, of a chemical nature eg measuring chlorine concentration in cooling water, of a sensory nature eg measurement of appearance and smell or of a microbiological test eg on a raw material. The choice of CCPs and the methodology applied to check that control is achieved, are very important parts of the HACCP procedure. They are the basis of the specifications that are used to assure microbiological safety and keepability of a food.

Verification
This is the use of supplementary information to ensure that the HACCP system has been properly installed and part of an audit procedure to check that it continues to function correctly.

It will often include microbiological and other tests requiring specialist laboratory facilities. For instance testing for *Salmonella* in milk powder, measuring the microbial load on equipment after sanitation, checking the a_W in an intermediate water activity product, or the gas mixture in a modified atmosphere pack.

Application
HACCP can be applied to an existing process or to a product at the development stage. For a detailed review of all applications, the reader is recommended to read the book recently published by the International Commission on Microbiological Specifications for Foods on principles and application of HACCP (ICMSF, 1988).

The system is applied in a formal structured way that begins with a systematic approach to hazard analysis based on HAZOPs (Hazard and Operability Studies) which is a procedure originally developed to identify hazards associated with handling chemicals in the chemical industry and adapted for use for microbiological hazards (Mayes and Kilsby, 1989), and for use with foods (Baird-Parker and Mayes, 1989).

The procedure culminates in a listing of all practices or procedures that could lead to the introduction of a specified hazard into the product or product component. The study team then ranks all such practices or procedures according to their probability of occurrence (risk), and identifies a number of control options (compatible with the company's overall QA strategy), to prevent each hazard occurring, or to mitigate its effects. Key control options are identified by the study team as Critical Control Points (CCPs) ie a location, practice or procedure where control *must* be exercised in order to prevent the realization of a hazard.

CCPs are ranked according to their importance in the control of identified microbiological concerns. There are various procedures. Thus ICMSF, (1988) recognises two types of CCP ie CCP1 and CCP2. A CCP1 is a CCP where a hazard can be controlled with a high level of certainty by a control procedure and the proper functioning of the control procedure can be continuously monitored. For instance, the use of a specified time and temperature in a pasteuriser to destroy vegetative bacteria, using a thermocouple to monitor that the temperature achieved in the pasteuriser is correct and an automatic divert valve that operates if temperature falls below a target value. A CCP2 on the other hand, whilst an important Control Point, may not effectively eliminate a hazard because the control or monitoring procedures are not totally effective. Thus the evisceration of a carcass (avoiding rupture of the intestine), the shelling of cooked prawns (avoiding recontamination), and the cleaning and disinfection of a surface between handling raw and cooked foods, are all CCPs but total control of the microbiological risks involved in these practices is not likely to be achievable and they are therefore classified as CCP2.

A different approach to ranking CCPs is used in the Campden Food & Drinks Research Association (1987) document on 'Guidance to the Establishment of Hazard Analysis Critical Control Points'. In this document, CCPs are ranked according to their commercial concern (combination of severity of hazard and risk) and the control procedure matched to the severity of the concern to be controlled. Thus they identify high, medium and low concerns and recommend that priorities for CCPs should be set in relationship to such ranked concerns, thus concentrating the key CCP's on the highest concerns (see also Mayes & Kilsby, 1989).

For HACCP and other Quality Assurance Procedures to be effective there is a need for commitment by all grades of staff in a factory and the full involvement of senior management. Whilst some expenditure of money is often necessary on equipment, procedures or training, the savings to be made by reduced rework, more consistent quality, improved safety and better shelf-life will usually more than balance this cost.

In a number of countries, authorities concerned with control of foods are actively considering the use of HACCP as part of legislation concerned with food hygiene. There is a need for industry to convince the authorities that a

properly evaluated and installed system of control based on HACCP gives the best possible assurance of microbiological safety (Figure 5). Such recognition will only be obtained by working closely with the authorities to agree procedures for applying HACCP and by permitting the authorities to review operations set up using the HACCP system. The authors believe that by applying the HACCP system throughout the food industry food poisoning risks will be brought under better control.

Figure 5
Benefits of HACCP to authorities and industry

(i) Objective assessment of hazards and risks of food production – from raw materials to product use.

(ii) Precise identification and definition of control and monitoring needs.

(iii) Better and more cost effective control – Critical Control Points help to allocate resources appropriately.

(iv) Reduction in public health and spoilage risks.

CONCLUSIONS

There is a wide range of procedures available for the safe and effective processing and preservation of foods. Data concerning the effects of these procedures on the inactivation, survival and potential for growth of food-poisoning micro-organisms are substantial and increasing rapidly in quantity and in ease of access. Access will further improve with the impending availability of easy-to-use data bases and expert systems, and an important element in bringing about a reduction in food poisoning risks will be the *use* of these data in an effective manner.

Experience has already taught us that structural approaches such as HACCP represent the most effective and workable means for introducing improvements in safety with respect to food processing, and also to all other elements of the food chain. Some industries and authorities may remain to be convinced. The authors believe that, with a sound data base to specify the precise requirement to control microbiological risks, wide application of HACCP will significantly reduce the incidence of food poisoning in this country.

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