THE MICROBIOLOGY OF FOOD PRESERVATION

Manipulation of the factors affecting microbial behaviour is the basis of food preservation (Table 4.1).

Table 4.1 Mechanisms of principal food preservation procedures

Procedure	*Factor influencing growth or survival*
Cooling, chill distribution and storage	Low temperature to retard growth
Freezing, frozen distribution and storage	Low temperature and reduction of water activity to prevent growth
Drying, curing and conserving	Reduction in water activity sufficient to delay or prevent growth
Vacuum and oxygen-free 'modified-atmosphere' packaging	Low oxygen tension to inhibit strict aerobes and delay growth of facultative anaerobes
Carbon dioxide-enriched 'modified-atmosphere' packaging	Specific inhibition of some micro-organisms by carbon dioxide
Addition of acids	Reduction of pH value and sometimes additional inhibition by the particular acid
Lactic fermentation	Reduction of pH value *in situ* by microbial action and sometimes additional inhibition by the lactic and acetic acids formed and by other microbial products, *e.g.* ethanol, bacteriocins
Emulsification	Compartmentalization and nutrient limitation within the aqueous droplets in water-in-oil emulsion foods
Addition of preservatives	Inhibition of specific groups of micro-organisms
Pasteurization and appertization	Delivery of heat sufficient to inactivate target micro-organisms to the desired extent
Radurization, radicidation and radappertization	Delivery of ionizing radiation at a dose sufficient to inactivate target micro-organisms to the desired extent
Application of high hydrostatic pressure Pascalization	Pressure-inactivation of vegetative bacteria, yeasts and moulds

HEAT PROCESSING

Pasteurization and Appertization

Foods are subject to thermal processes in a number of different contexts (Table 4.2). Often, their main objective is not destruction of microorganisms in the product, although this is an inevitable and

frequently useful side effect. Pasteurization, the term given to heat processes typically in the range 60-80°C and applied for up to a few minutes, is used for two purposes.

First is the elimination of a specific pathogen or pathogens associated with a product. This type of pasteurization is often a legal requirement introduced as a public health measure when a product has been frequently implicated as a vehicle of illness. Notable examples are milk, bulk liquid egg and ice cream mix, all of which have a much improved safety record as a result of pasteurization. The second reason for pasteurizing a product is to eliminate a large proportion of potential spoilage organisms, thus extending its shelf-life. This is normally the objective when acidic products such as beers, fruit juices, pickles, and sauces are pasteurized.

Table 4.2 Heat processes applied to foods

Heat process	*Temperature*	*Objective*
Cooking baking boiling frying grilling	⩽100 °C	Improvement of digestibility, *e.g.* starch gelatinization, collagen breakdown during cooking of meat Improvement of flavour Destruction of pathogenic micro-organisms
Blanching	<100 °C	Expulsion of oxygen from tissues Inactivation of enzymes
Drying/Concentration	<100 °C	Removal of water to enhance keeping quality
Pasteurization	60–80 °C	Elimination of key pathogens and spoilage organisms
Appertization	>100 °C	Elimination of micro-organisms to achieve 'commercial sterility'

On its own, the contribution of pasteurization to extension of shelf-life can be quite small, particularly if the pasteurized food lacks other contributing preservative factors such as low pH or a,. Thermoduric organisms such as spore formers and some Grampositive vegetative species in the genera *Enterococcus*, *Microbacterium* and *Arthrobacter*

can survive pasteurization temperatures. They can also grow and spoil a product quite rapidly at ambient temperatures, so refrigerated storage is often an additional requirement for an acceptable shelf-life.

Heat Sensitivity of Microorganisms

The heat sensitivity of various microorganisms is illustrated by Table 4.3 which shows their D values. Generally psychrotrophs are less heat resistant than mesophiles, which are less heat resistant than thermophiles; and Gram-positives are more heat resistant than Gram-negatives. Most vegetative cells are killed almost instantaneously at 100°C and their D values are measured and expressed at temperatures appropriate to pasteurization.

Table 4.3 Microbial heat resistance

Vegetative organisms (z ~ 5 °C)	*D (mins)*	
Salmonella sp.	D_{65}	0.02–0.25
Salmonella Seftenberg	D_{65}	0.8–1.0
Staphylococcus aureus	D_{65}	0.2–2.0
Escherichia coli	D_{65}	0.1
Yeasts and moulds	D_{65}	0.5–3.0
Listeria monocytogenes	D_{60}	5.0–8.3
Campylobacter jejuni	D_{55}	1.1
Bacterial Endospores (z ~ 10 °C)	D_{121}	
B. stearothermophilus		4–5
C. thermosaccharolyticum		3–4
Desulfotomaculum nigrificans		2–3
B. coagulans		0.1
C. botulinum types A & B		0.1–0.2
C. sporogenes		0.1–1.5
C. botulinum type E	D_{80}	0.1–3.0
	D_{110}	< 1 second

Bacterial spores are usually far more heat resistant than vegetative cells; thermophiles produce the most heat resistant spores while those of psychrotrophs and psychrophiles are most heat sensitive. Since spore inactivation is the principal concern in producing appertized foods, much higher temperatures are used in appertization processes and in the measurement of spore D values.

Yeast ascospores and the asexual spores of moulds are only slightly more heat resistant than the vegetative cells and will normally be killed by temperatures at or below 100°C, e.g. in the baking of bread. Ascospores of the mould Byssochlamys fulva, and a few other ascomycetes do show a more marked heat resistance and can be an occasional cause of problems in canned fruits which receive a relatively mild heat process.

The heat resistance exhibited by the bacterial endospore is due mainly to its ability to maintain a very low water content in the central DNA-containing protoplast; spores with a higher water content have a lower heat resistance.

Spoilage of Canned Foods

If a canned food contains viable micro-organisms capable of growing in the product at ambient temperatures, then it will spoil. Organisms may be present as a result of an inadequate heat process, underprocessing, or of post process contamination through container leakage. Spoilage by a single spore former is often diagnostic of underprocessing since rarely would such a failure be so severe that vegetative organisms would survive.

A normal sound can will either be under vacuum with slightly concave ends or have flat ends in those cases where the container is brimful. Spoilage often manifests itself through microbial gas production which causes the ends to distend and a number of different terms are used to describe the extent to which this has occurred (Table 4.6). The spore-forming anaerobes Clostridium can be either predominantly proteolytic or saccharolytic but both activities are normally accompanied by gas production causing the can to swell. Cans may sometimes swell as a result of chemical action. Defects in the protective lacquer on the inside of the can may allow the contents to attack the metal releasing hydrogen. These hydrogen swells can often be distinguished from microbiological spoilage since the appearance of swelling occurs after long periods of storage and the rate at which the can swells is usually very slow.

In cases where microbial growth occurs without gas production, spoilage will only be apparent once the pack has been opened. *Bacillus* species, with the exceptions of *B. macerans* and *B. polymyxa*, usually break down carbohydrates to produce acid but no gas giving a type of spoilage known as a ‘flat sour’, which describes the characteristics of both the can and the food. A product's acidity also determines the type of spoilage that may result from underprocessing since it can prevent the growth of some spoilage organisms. At normal ambient temperatures (< 38˚C) only mesophilic species will grow. Typical examples would be *C. botulinum*, *C. sporogenes* and *B. subtilis* in low acid products and *C. butyricum* and *C. pasteurianum* in products with a pH below 4.5. Cans are cooled rapidly after processing to prevent spoilage by thermophiles.

Thermophilic organisms commonly associated with spoilage of low acid canned foods are the saccharolytic organism *C. thermosaccharolyticum, B. stearothermophilus* and *Desulfotomaculum nigrijicans*. The last of these causes a type of spoilage known as 'sulfur stinker'. It produces hydrogen sulfide which does not usually distend the can but does give the product an objectionable smell and reacts with iron from the can to cause blackening. Leakage is the most common cause of microbiological spoilage in canned foods.

Aseptic Packaging

Up until now in our consideration of appertized foods we have discussed only retorted products; those which are hermetically sealed into containers, usually cans, and then subjected to an appertizing heat process in-pack. In UHT processing the food is heat processed before it is packed and then sealed into sterilized containers in a sterile environment. This approach allows more rapid heating of the product, the use of higher temperatures than those employed in canning, typically 130- 140˚C, and processing times of seconds rather than minutes.

Initially UHT processing and aseptic packaging were confined to liquid products such as milk, fruit juices and some soups which would heat up

very quickly due to convective heat transfer. If a food contained solid particles larger than about 5mm diameter it was unsuited to the rapid processing times due to the slower conductive heating of the particulate phase.

IRRADIATION

Electromagnetic (e.m.) radiation is a way in which energy can be Propagated through space. As far as food microbiology is concerned, only three areas of the e.m. spectrum concern us; microwaves, the UV region and gamma rays. We will now consider each of these in turn.

Microwave Radiation

The microwave region of the e.m. spectrum occupies frequencies between l09 Hz up to 10l2 Hz. Microwaves act indirectly on micro-organisms through the generation of heat. When a food containing water is placed in a microwave field, the dipolar water molecules align themselves with the field. As the field reverses its polarity 2 or 5 x lo9 times each second, depending on the frequency used, the water molecules are continually oscillating.

Microwaves have been slow to find industrial applications in food processing, although they are used in a number of areas. Microwaves have been used to defrost frozen blocks of meat prior to their processing into products such as burgers and pies thus reducing wear and tear on machinery. There has also been a limited application of microwaves in the blanching of fruits and vegetables and in the pasteurization of soft bakery goods and moist (30% H20) pasta to destroy yeasts and moulds. In Japan, microwaves have been used to pasteurize high-acid foods, such as fruits in syrup, intended for distribution at ambient temperature. These are packed before processing and have an indefinite microbiological shelf-life because of the heat process and their low pH. However, the modest oxygen barrier properties of the pack has meant that their biochemical shelf-life is limited to a few months.

UV Radiation

UV radiation has wavelengths below 450 nm and chemical reactions thus induced in micro-organisms can cause the failure of critical metabolic processes leading to injury or death. Photochemical reactions will inhibit microorganisms, so those wavelengths that are most effective give us an indication of the sensitive chemical targets within the cell. The greatest lethality is shown by wavelengths around 260 nm which correspond to a strong absorption by nucleic acid bases. The pyrimidine bases appear particularly sensitive, and UV light at this wavelength will, among other things, induce the formation of covalently linked dimers between adjacent thymine bases in DNA. If left intact these will prevent transcription and DNA replication in affected cells.

The resistance of microorganisms to UV is largely determined by their ability to repair such damage, although some organisms such as micrococci also synthesize protective pigments

Ionizing Radiation

Ionizing radiation can affect micro-organisms directly by interacting with key molecules within the microbial cell, or indirectly through the inhibitory effects of free radicals produced by the radiolysis of water. These indirect effects play the more important role since in the absence of water, doses 2-3 times higher are required to obtain the same lethality. Removal of oxygen also increases microbial resistance 2-4 fold and it is thought that this may be due to the ability of oxygen to participate in free radical reactions and prevent the repair of radiation induced lesions. As with UV irradiation, the main site of damage in cells is the chromosome. Hydroxyl radicals cause single- and double-strand breaks in the DNA molecule as a result of hydrogen abstraction from deoxyribose followed by p-elimination of phosphate which cleaves the molecule. They can also hydroxylate purine and pyrimidine bases.

Food-associated organisms do not generally display exceptional resistance, although spores of some strains of Clostridium botulinum type A have the most radiation resistant spores. Since studies on food

irradiation started, a number of bacteria which are highly resistant to radiation have been isolated and described. Although one of these, *Deinococcus radiodurans*, was first isolated from meat, their role in foods is not

Two terms are used to distinguish different types of radiation pasteurization. Radicidation is used to describe processes where the objective is the elimination of a pathogen, as, for example, in the removal of Salmonella from meat and poultry. Radurization applies to processes aiming to prolong shelf-life. This distinction may be thought a little over elaborate since, as with thermal pasteurization, irradiation treatments are relatively non-discriminating and will invariably improve both safety and shelf-life.significant in the normal course of events.

LOW-TEMPERATURE STORAGE - CHILLING AND FREEZING

The rates of most chemical reactions are temperature dependent; as the temperature is lowered so the rate decreases. Since food spoilage is usually a result of chemical reactions mediated by microbial and endogenous enzymes, the useful life of many foods can be increased by storage at low temperatures. Since then, use of chilling and freezing has extended to a much wider range of perishable foods and to such an extent that refrigeration is now arguably the technology of paramount importance to the food industry.

Chill Storage

Chilled foods are those foods stored at temperatures near, but above their freezing point, typically 0-5 "C. This commodity area has shown a massive increase in recent years as traditional chilled products such as fresh meat and fish and dairy products have been joined by a huge variety of new products including complete meals, prepared and delicatessen salads, dairy desserts and many others. Three main factors have contributed to this development:

(1) The food manufacturers' objective of increasing added value to their products;

(2) consumer demand for fresh foods while at the same time requiring the convenience of only occasional shopping and ease of preparation; and

(3) the availability of an efficient cold chain - the organization and infrastructure which allows low temperatures to be maintained throughout the food chain from manufacture/harvest to consumption.

Chill storage can change both the nature of spoilage and the rate at which it occurs. There may be qualitative changes in spoilage characteristics, as low temperatures exert a selective effect preventing the growth of mesophiles and leading to a microflora dominated by psychrotrophs. Low temperatures can also cause physiological changes in micro-organisms that modify or exacerbate spoilage characteristics. Two such examples are the increased production of phenazine and carotenoid pigments in some organisms at low temperatures and the stimulation of extracellular polysaccharide production in *Leuconostoc* spp. and some other lactic acid bacteria. In most cases, such changes probably represent a disturbance of metabolism due to the differing thermal coefficients and activation energies of the numerous chemical reactions that comprise microbial metabolism.

Though psychrotrophs can grow in chilled foods they do so only relatively slowly so that the onset of spoilage is delayed. In this respect temperature changes within the chill temperature range can have pronounced effects. For example, the generation time for one *Pseudomonas* isolated from fish was 6.7 hours at 5°C compared with 26.6 hours at 0°C. Where this organism is an important contributor to spoilage, small changes of temperature will have major implications for shelf-life.

Though mesophiles cannot grow at chill temperatures, they are not necessarily killed. Chilling will produce a phenomenon known as cold shock which causes death and injury in a proportion of the population but its effects are not predictable in the same way as heat processing. The extent of cold shock depends on a number of factors such as the

organism (Gram-negatives appear more susceptible than Gram-positives), its phase of growth (exponential-phase cells are more susceptible than stationary phase cells), the temperature differential and the rate of cooling (in both cases the larger it is, the greater the damage), and the growth medium (cells grown in complex media are more resistant).

Since chilling is not a bacteriocidal process, the use of good microbiological quality raw materials and hygienic handling are key requirements for the production of safe chill foods. Mesophiles that survive cooling, albeit in an injured state, can persist in the food for extended periods and may recover and resume growth should conditions later become favourable. Thus chilling will prevent an increase in the risk from mesophilic pathogens, but will not assure its elimination. There are however pathogens that will continue to grow at some chill temperatures and the key role of chilling in the modern food industry has focused particular attention on these.

Freezing

Freezing is the most successful technique for long-term preservation of food since nutrient content is largely retained and the product resembles the fresh material more closely than in appertized foods.

Foods begin to freeze somewhere in the range -0.5 to -3℃, the freezing point being lower than that of pure water due to the solutes present. As water is converted to ice during freezing, the concentration of solutes in the unfrozen water increases, decreasing its freezing point still further so that even at very low temperatures, e.g. -60℃, some water will remain unfrozen. The temperatures used in frozen storage are generally less than -18℃. At these temperatures no microbial growth is possible, although residual microbial or endogenous enzyme activity such as lipases can persist and eventually spoil a product. This is reduced in the case of fruits and vegetables by blanching before freezing to inactivate endogenous polyphenol oxidases which would otherwise cause the product to discolour during storage. Freezer burn is another non-

microbiological quality defect that may arise in frozen foods, where surface discolouration occurs due to sublimation of water from the product and its transfer to colder surfaces in the freezer. This can be prevented by wrapping products in a water-impermeable material or by glazing with a layer of ice.

Low temperature is not the only inhibitory factor operating in frozen foods; they also have a low water activity produced by removal of water in the form of ice. As far as microbiological quality is concerned, this effect is only significant when frozen foods are stored at temperatures where microbial growth is possible (above -10˚C). In this situation, the organisms that grow on a product are not those normally associated with its spoilage at chill temperatures but yeasts and moulds that are both psychrotrophic and tolerant of reduced water activity. Thus meat and poultry stored at - 5 to - 10˚C may slowly develop surface defects such as black spots due to the growth of the mould *Cladosporium herbarum*, white spots caused by *Sporotrichum carnis* or the feathery growth of *Thamnidium elegans*.

Freezing and defrosting may make some foods more susceptible to microbiological attack due to destruction of antimicrobial barriers in the product and condensation, but defrosted foods do not spoil more rapidly than those that have not been frozen. Injunctions against refreezing defrosted products are motivated by the loss of textural and other qualities rather than any microbiological risk that is posed.

HIGH-PRESSURE PROCESSING - PASCALIZATION

Hite, working at the University of West Virginia Agricultural Experimental Station at the turn of the century, showed that high hydrostatic pressures, around 650 MPa (6500 atm), reduced the microbial load in foods such as milk, meats and fruits. He found that 680 MPa applied for 10 min at room temperature reduced the viable count of milk from 10^7 cfu ml^{-1} to 10^1 – l0 ^{2} cfu ml^{-1} and that peaches and pears subjected to 410 MPa for 30 min remained in good condition after 5

years storage. He also noted that the microbicidal activity of high pressure is enhanced by low pH or temperatures above and below ambient.

High hydrostatic pressure acts primarily on non-covalent linkages, such as ionic bonds, hydrogen bonds and hydrophobic interactions, and it promotes reactions in which there is an overall decrease in volume. It can have profound effects on proteins, where such interactions are critical to structure and function, although the effect is variable and depends on individual protein structure. Some proteins such as those of egg, meat and soya form gels and this has been employed to good effect in Japan where high pressure has been used to induce the gelation of fish proteins in the product surimi.

Adverse effects on protein structure and activity obviously contribute to the antimicrobial effect of high pressures, although the cell membrane also appears to be an important target. Membrane lipid bilayers have been shown to compress under pressure and this alters their permeability. As a general rule vegetative bacteria and fungi can be reduced by at least one log cycle by 400 MPa applied for 5 min.

CHEMICAL PRESERVATIVES

The addition of chemicals to food is not a recent innovation but has been practised throughout recorded history. Preservatives are defined as ‘substances capable of inhibiting, retarding or arresting the growth of micro-organisms or of any deterioration resulting from their presence or of masking the evidence of any such deterioration’.

Preservatives may be microbicidal and kill the target organisms or they may be microbistatic in which case they simply prevent them growing.

Organic Acids and Esters

The most important organic acids and esters that are used as food preservatives are listed in Table 4.12. The antimicrobial effect of organic

acids such as acetic and lactic acids, both are produced microbiologically, although food-grade acetic acid derived petrochemically is also sometimes used as an alternative to vinegar.

Benzoic acid occurs naturally in cherry bark, cranberries, greengage plums, tea and anise but is prepared synthetically for food use. Its antimicrobial activity is principally in the undissociated form and since it is a relatively strong acid, it is effective only in acid foods.

Parabens (para-hydroxybenzoic acid esters) differ from the other organic acids described here in the respect that they are phenols rather than carboxylic acids. They are much weaker acids with pK, values of 8.5 and so are predominantly uncharged even at neutral pH. This means that they can be used effectively in non-acidic foods. Their antimicrobial activity increases with the length of the ester group carbon chain, although this also decreases their water solubility and may lead to poor performance in some foods where partition into the fatty phase may occur. Some Gram-negatives are resistant to the higher homologues and this has been ascribed to the cell’s outer membrane acting as a barrier.

Sorbic acid is an unsaturated fatty acid, 2,4-hexadienoic acid, found naturally in the berries of the mountain ash. It has a PKa of 4.8 and shows the same pH dependency of activity as other organic acids. It is active against yeasts, moulds and catalase-positive bacteria but, interestingly, is less active against catalase-negative bacteria. This has led to its use as a selective agent in media for clostridia and lactic acid bacteria and as a fungal inhibitor in lactic fermentations.

Propionic acid (pKa 4.9) occurs in a number of plants and is also produced by the activity of propionibacteria in certain cheeses. It is used as a mould inhibitor in cheese and baked products where it also inhibits rope-forming bacilli.

Table 4.12 Organic acid food preservatives

Preservative	**ADI (mg kg^{-1}* body wt).	Typical usage and levels	(mg kg^{-1})
E200 Sorbic acid E201 Sodium salt E202 Potassium salt E203 Calcium salt	25	Salad dressing bakery products fruit desserts	<2000
E210 Benzoic acid E211 Sodium salt E212 Potassium salt E213 Calcium salt	5	Cider, soft drinks, fruit products, bottled sauces	<3000
E260 Acetic acid	No limit	Pickles, sauces chutneys	up to % levels (1%=10 000mg kg^{-1})
E270 Lactic acid	No limit	Fermented meats dairy and vegetable products. Sauces and dressings. Drinks.	up to % levels (1%=10 000mg kg^{-1})
E280 Propionic acid E281 Sodium salt E282 Calcium salt E283 Potassium salt	10	Bakery goods Cheese spread	1000–5000
Parabens E214 *p*-Hydroxybenzoic acid ethyl ester E215 Sodium salt	10	Bakery goods, pickles, fruit products, sauces	<2000
E216 *p*-Hydroxybenzoic acid n-propyl ester E217 Sodium salt		Bakery goods, pickles, fruit products, sauces	<2000
E218 *p*-Hydroxybenzoic acid methyl ester E219 Sodium salt		Bakery goods, pickles, fruit products, sauces	<2000

Nitrite

The antibacterial action of nitrite was first described in the 1920s though it had long been employed unknowingly in the production of cured meats where it is also responsible for their characteristic colour and flavour.

Nitrite is inhibitory to a range of bacteria. Early workers showed that a level of 200 mg kg^{-1} at pH 6.0 was sufficient to inhibit strains of *Escherichia*, *Flavobacterium*, *Micrococcus*, *Pseudomonas* and others, although Salmonella and Lactobacillus species were more resistant. Of

most practical importance though is the ability of nitrite to inhibit spore-forming bacteria such as *Clostridium botulinum* which will survive the heat process applied to many cured meats. To achieve this commercially, initial levels of nitrite greater than 100 mg kg^{-1} are used. The mechanism of its action is poorly understood partly due to the complexity of the interaction of several factors such as pH, salt content, presence of nitrate or nitrite and the heat process applied to the cured meat.

Sulfur Dioxide

Sulfur dioxide (SO_2) has long enjoyed a reputation for its disinfecting properties and its earliest use in the food industry was when sulfur candles were burnt to disinfect the vessels used to produce and store wine. Nowadays, it is also used as an antioxidant to inhibit enzymic and non-enzymic browning reactions in some products.

The unionized forms of SO_2 which can readily penetrate the cell have the greatest antimicrobial activity. It has been reported that they are between 100 and 1000 times more active than the bisulfite anion. Since the unionized forms predominate at low pH values, it follows that SO_2 is used to best effect in acidic foods.

Sulfur dioxide is active against bacteria, yeasts and moulds, although some yeasts and moulds are more resistant. Gram-negative bacteria are most susceptible and in British fresh sausage where sulfite is permitted up to a level of 450 mg kg^{-1} the Gram-negative spoilage flora normally associated with chilled meats is replaced by one dominated by Grampositive bacteria and yeasts. In winemaking the tolerance of the wine yeast *Saccharomyces cerevisiae* to SO_2 levels around 100 mg/l is exploited to control the growth of wild yeasts and acetifying bacteria. Seasonal surpluses of soft fruits are also preserved by the addition of high levels of SO_2 to permit jam production throughout the year.

‘Natural’ Food Preservatives

Smoking of foods might be viewed as a natural method of preservation. Its antimicrobial effect is a result of drying and the activity of woodsmoke

components such as phenols and formaldehyde which would probably not be allowed were they to be proposed as chemical preservatives in their own right. The use of natural food components possessing antimicrobial activity such as essential oils and the lactoperoxidase system in milk have attracted some attention in this respect. Attention has also been paid to the bacteriocins produced by food-grade micro-organisms such as the lactic acid bacteria. Nisin is an already well established example and its use can be extended by expedients such as inclusion of whey fermented by a nisin producing strain of *Lactococcus lactis* as an ingredient in formulated products like prepared sauces

MODIFICATION OF ATMOSPHERE

At the start of the 19th century it was believed that contact with air caused putrefaction and that food preservation techniques worked by excluding air. Modified atmospheres exert their effect principally through the inhibition of fast-growing aerobes that would otherwise quickly spoil perishable products. Obligate and facultative anaerobes such as *clostridia* and the *Enterobacteriaceae* are less affected. Thus keeping quality is improved but there is generally little effect on pathogens, if present, and the technique is invariably applied in conjunction with refrigerated storage.

In practice three different procedures are used to modify the atmosphere surrounding a product: vacuum packing, modified-atmosphere packing or gas flushing, and controlled atmospheres.

In vacuum packing the product is placed in a bag from which the air is evacuated, causing the bag to collapse around the product before it is sealed. Residual oxygen in the pack is absorbed through chemical reactions with components in the product and any residual respiratory activity in the product and its microflora. To achieve the best results, it is important that the material to be packed has a shape that allows the packaging film to collapse on to the product surface entirely – without pockets and without the product puncturing the film.

In modified atmosphere packing (MAP) a bulk or retail pack is flushed through with a gas mixture usually containing some combination of carbon dioxide, oxygen and nitrogen. The composition of the gas atmosphere changes during storage as a result of product and microbial respiration, dissolution of CO2 into the aqueous phase, and the different rates of gas exchange across the packing membrane. These changes can be reduced by increasing the ratio of pack volume to product mass although this is not often practicable for other reasons.

Carbon dioxide is included for its inhibitory effect, nitrogen is non-inhibitory but has low water solubility and can therefore prevent pack collapse when high concentrations of CO_2 are used. By displacing oxygen it can also delay the development of oxidative rancidity.

In controlled-atmosphere storage (CAP) the product environment is maintained constant throughout storage. It is used mainly for bulk storage and transport of foods, particularly fruits and vegetables, such as the hard cabbages used for coleslaw manufacture. CAP is used for shipment of chilled lamb carcasses and primal cuts which are packed in an aluminium foil laminate bag under an atmosphere of 100% CO_2. It is more commonly encountered though with fruits such as apples and pears which are often stored at sub-ambient temperatures in atmospheres containing around 10% CO_2. This has the effect of retarding mould spoilage of the product through a combination of the inhibitory.

CONTROL OF WATER ACTIVITY

The water activity of a product can be reduced by physical removal of liquid water either as vapour in drying, or as a solid during freezing. It is also lowered by the addition of solutes such as salt and sugar. The primal role of these techniques in food preservation has been alluded to in a number of places. It was the earliest food preservation technique and, until the 19th century, water activity reduction played some part in almost all the known procedures for food preservation.

Nature provided early humans with an object lesson in the preservative

value of high solute concentrations in the form of honey produced by bees from the nectar of plants. The role of salt in decreasing a_w accounts for its extreme importance in the ancient economy.

Solar drying, while perhaps easy and cheap, is subject to the vagaries of climate. Drying indoors over a fire was one way to avoid this problem and one which had the incidental effect of imparting a smoked flavour to the food as well as the preservative effect of chemical components of the smoke.

Salting and drying in combination have played a central role in the human diet until very recently. One instance of this is the access it gave the population of Europe to the huge catches of cod available off Newfoundland. From the end of the 15th century, salted dried cod was an important item in trans-Atlantic trade and up until the 18th century accounted for 60% of all the fish eaten in Europe.

Among the main features of the effect of a_w on the growth and survival of microorganisms does not occur below a_w of 0.6. This applies to a number of food products, but the fact that microbial spoilage is not possible given proper storage conditions, does not mean that they do not pose any microbiological problems. Microorganisms that were in the product before drying or were introduced during processing can survive for extended periods. This is most important with respect to pathogens if they were present in hazardous numbers before drying or if time and temperature allow them to resume growth in a product that is rehydrated before consumption. There have been a number of instances where the survival of pathogens or their toxins has caused problems in products such as chocolate, pasta, dried milk and eggs. Generally *Salmonella* and *Staphylococcus aureus* have been the principal pathogens involved - there have been 17 major outbreaks associated with these organisms and dried milk in the last 40 years, but spore formers are particularly associated with some other dried products such as herbs or rice.

Intermediate moisture foods (IMFs), are commonly defined as those

foods with a_w between 0.85 and 0.6. This range, which corresponds roughly to a moisture content of 15-50%, prohibits the growth of Gram-negative bacteria as well as a large number of Gram-positives, yeasts and moulds, giving the products an extended shelf-life at ambient temperature. When spoilage does occur, it is often a result of incorrect storage in a high relative humidity environment. In correctly stored products growth of xerophilic moulds, osmophilic yeasts or halophilic bacteria may occur, depending on the product, and in many IMFs the shelf-life is further protected by the inclusion of antifungal agents such as sulfur dioxide or sorbic acid.

At the a_w of IMFs, pathogens are also prevented from growing. Although *Staph*. *aureus* is capable of growing down to an a, of 0.83, it cannot produce toxin and is often effectively inhibited by the combination of a_w with other antimicrobial hurdles.

There are a number of traditional IMFs such as dried fruits, cakes, jams, fish sauce and some fermented meats. Sweetened condensed milk is one interesting example. Milk is homogenized, heated to 80˚C and sugar added before it is concentrated in a multi-effect vacuum evaporator at 50-60˚C. Its stability is a result of its high sugar content (62.5% in the aqueous phase) and low a_w (<0.86).

Spoilage may sometimes occur due to growth of osmophilic yeasts or, if the can is under-filled leaving a headspace, species of *Aspergillus* or *Penicillium* may develop on the surface.

Solar drying is still widely practised in hot climates for products such as fruits, fish, coffee and grain. The traditional technique of spreading the product out in the sun with occasional turning often gives only rudimentary or, sometimes, no protection from contamination by birds, rodents, insects and dust. Though in tropical countries with high humidity drying is usually slower so that products such as fish are often pre-salted to inhibit microbial growth during drying.

There are a number of procedures for mechanical drying which are

quicker, more reliable, albeit more expensive than solar drying. The drying regime must be as rapid as possible commensurate with a highquality product so factors such as reconstitution quality must also be taken into account.

the product through a combination of the inhibitory.

CONTROL OF WATER ACTIVITY

The water activity of a product can be reduced by physical removal of liquid water either as vapour in drying, or as a solid during freezing. It is also lowered by the addition of solutes such as salt and sugar. The primal role of these techniques in food preservation has been alluded to in a number of places. It was the earliest food preservation technique and, until the 19th century, water activity reduction played some part in almost all the known procedures for food preservation.

Nature provided early humans with an object lesson in the preservative value of high solute concentrations in the form of honey produced by bees from the nectar of plants. The role of salt in decreasing a_w accounts for its extreme importance in the ancient economy.

Solar drying, while perhaps easy and cheap, is subject to the vagaries of climate. Drying indoors over a fire was one way to avoid this problem and one which had the incidental effect of imparting a smoked flavour to the food as well as the preservative effect of chemical components of the smoke.

Salting and drying in combination have played a central role in the human diet until very recently. One instance of this is the access it gave

the population of Europe to the huge catches of cod available off Newfoundland. From the end of the 15th century, salted dried cod was an important item in trans-Atlantic trade and up until the 18th century accounted for 60% of all the fish eaten in Europe.

Among the main features of the effect of a_w on the growth and survival of microorganisms does not occur below a_w of 0.6. This applies to a number of food products, but the fact that microbial spoilage is not possible given proper storage conditions, does not mean that they do not pose any microbiological problems. Microorganisms that were in the product before drying or were introduced during processing can survive for extended periods. This is most important with respect to pathogens if they were present in hazardous numbers before drying or if time and temperature allow them to resume growth in a product that is rehydrated before consumption. There have been a number of instances where the survival of pathogens or their toxins has caused problems in products such as chocolate, pasta, dried milk and eggs. Generally *Salmonella* and *Staphylococcus aureus* have been the principal pathogens involved - there have been 17 major outbreaks associated with these organisms and dried milk in the last 40 years, but spore formers are particularly associated with some other dried products such as herbs or rice.

Intermediate moisture foods (IMFs), are commonly defined as those foods with a_w between 0.85 and 0.6. This range, which corresponds roughly to a moisture content of 15-50%, prohibits the growth of Gram-negative bacteria as well as a large number of Gram-positives, yeasts and moulds, giving the products an extended shelf-life at ambient temperature. When spoilage does occur, it is often a result of incorrect storage in a high relative humidity environment. In correctly stored products growth of xerophilic moulds, osmophilic yeasts or halophilic bacteria may occur, depending on the product, and in many IMFs the shelf-life is further protected by the inclusion of antifungal agents such as sulfur dioxide or sorbic acid.

At the a_w of IMFs, pathogens are also prevented from growing. Although

Staph. *aureus* is capable of growing down to an a, of 0.83, it cannot produce toxin and is often effectively inhibited by the combination of a_w with other antimicrobial hurdles.

There are a number of traditional IMFs such as dried fruits, cakes, jams, fish sauce and some fermented meats. Sweetened condensed milk is one interesting example. Milk is homogenized, heated to 80˚C and sugar added before it is concentrated in a multi-effect vacuum evaporator at 50-60˚C. Its stability is a result of its high sugar content (62.5% in the aqueous phase) and low a_w (<0.86).

Spoilage may sometimes occur due to growth of osmophilic yeasts or, if the can is under-filled leaving a headspace, species of *Aspergillus* or *Penicillium* may develop on the surface.

Solar drying is still widely practised in hot climates for products such as fruits, fish, coffee and grain. The traditional technique of spreading the product out in the sun with occasional turning often gives only rudimentary or, sometimes, no protection from contamination by birds, rodents, insects and dust. Though in tropical countries with high humidity drying is usually slower so that products such as fish are often pre-salted to inhibit microbial growth during drying.

There are a number of procedures for mechanical drying which are quicker, more reliable, albeit more expensive than solar drying. The drying regime must be as rapid as possible commensurate with a high quality product so factors such as reconstitution quality must also be taken into account.