Gilbert, S.G., Harzidimitriu, E., Lai, C. and Passy, N. (1982) Study of barrier properties of polymeric films to various organic aromatic vapors, in *Instrumental Analyses of Food* (eds G. Charalambous and G. Inglett), Vol. 1, 405.

Gill, M. (1990) High permeability films for MAP of fresh produce. *International Conference on MAP*. Campden Food and Drink Research Association, Chipping Campden, Gloucestershire.

Granzer, R. (1982) *Proceedings of the International Congress of Fruit Juice Producers*, Munich.

Greengrass, J. (1993) Films for MAP of foods, in *Principles and Applications of Modified Atmosphere Packaging of Foods* (ed. R.T. Parry), Blackie Academic & Professional, Glasgow, 63–100.

Haydanek, M.G., Woolford, G. and Baugh, L.B. (1970) Premiums and coupons as potential sources of objectionable flavor in cereal products. *J. Food Sci.*, **44**(3), 850.

Hirose, K., Harte, B., Giacin, J., Miltz, J. and Stine, C. (1988) Sorption of d-limonene by sealant films and effect on mechanical properties, in *Food and Packaging Interactions* (ed. J. Hotchkiss), ACS Symposium Series 365, Washington DC.

Hobbs, J.P., Anand, M. and Campion, B.A. (1990) Fluorinated high-density polyethylene barrier containers, in *Barrier Polymers and Structures* (ed. W.J. Koros), ACS Symposium Series 423, Washington DC.

Kern, C.L. Jr. (1989) High-performance polyester for food and beverage packaging. *Food Technol.*, **43**(12), 93.

Kwapong, O.Y. and Hotchkiss, J.H. (1987) Comparative sorption of aroma compounds by polyethylene and ionomer food contact plastics. *J. Food Sci.*, **52**(3), 761.

LaBell, F. (1991) Edible packaging. *Food Proc.*, **52**(12), 24.

Labuza, T.P. and Breene, W.M. (1989) Applications of 'active packaging' for improvement of shelf-life and nutritional quality of fresh and extended shelf-life food. *J. Food Proc. Preserv.*, **13**(1), 31.

Lopez, A.A. (1987) *A Complete Course in Canning and Related Processing*, 12th edn; The Canning Trade Inc., Baltimore, Maryland.

Maeda, H., Takahashi, Y. and Ifuku, Y. (1984) Adsorption of citrus nastsudaidai Hayata juice with polyvinyl pyrrolidone, Nylon 66 and high porous polymer. *Nippon Shokuhin Kogyo Gakkaishi*, **26**, 1.

Mannheim, C.H., Miltz, J., Ben-Aryie, G. and Lavie, R. (1985) *Interaction Between Carton Packages and Aseptically Packed Citrus Juice*. Presented at the 45th Annual IFT National Meeting, Atlanta, Abstract 131.

Mannheim, C.H., Miltz, J. and Letzer, A. (1987) Interaction between polyethylene laminated cartons and aseptically packed citrus juices. *J. Food Sci.*, **52**(3), 737.

Mannheim, C.H., Miltz, J. and Passy, N. (1988) Interaction between aseptically filled citrus products and laminated structures, in *Food and Packaging Interactions* (ed. J. Hotchkiss), ACS Symposium Series 365, Washington DC.

Marin, A.B., Acree, T.E., Hotchkiss, J.H. and Nagy, S. (1992) Gas chromatography-olfactometry of orange juice to assess the effects of plastic polymers on aroma character. *J. Agric. Food Chem.*, **40**, 650.

Marshall, M.R., Adams, J.P. and Williams, J.W. (1985) Flavor absorption by aseptic packaging material. *Proceedings ASEPTIPAK 85*, Princeton, New Jersey.

Meadows, P. (1991) Building barriers. *Packaging Today*, **October**, 59.

Miltz, J. (1992) Food packaging, in *Handbook of Food Engineering* (eds D.R. Heldman and D.B. Lund), Marcel Dekker, New York.

Miltz, J., Mannheim, C.H. and Harte, B.R. (1990) Packaging of juices using polymeric barrier containers, in *Barrier Polymers and Structures* (ed. W.J. Koros), ACS Symposium Series 423, Washington DC.

Moshonas, M.G. and Lund, E.D. (1969) Aldehydes, ketones and esters in Valencia orange peel. *J. Food Sci.*, **34**(2), 502.

Moshonas, M.G. and Shaw, P.E. (1989) Flavor evaluation and volatile flavor constituents of stored aseptically packaged orange juice. *J. Food Sci.*, **54**.

Osajima, Y. (1983) *Study on the Influence of Plastic Films Against the Food Aroma*, Japan Food Industry Bulletin.

Parry, R.T. (ed.) (1993) *Principles and Applications of Modified Atmosphere Packaging of Foods*, Blackie Academic & Professional, Glasgow.

Pieper, G., Borgudd, L., Ackermann, P. and Fellers, P. (1992) Absorption of aroma volatiles of orange juice into laminated carton packages did not affect sensory quality. *J. Food Sci.*, **57**(6), 1408.

Rice, J. (1992a) Silica-coated plastic packaging. *Food Proc. (Am.)*, **53**(6), 78.

Rice, J. (1992b) Silica-coated films to go commercial in '93. *Food Proc. (Am.)*, **53**(10), 82.

Shimoda, M., Ikegami, T. and Osajima, Y. (1988) Sorption of flavor compounds in aqueous solution into polyethylene film. *J. Food Sci. Agric.*, **42**, 157.

Shimoda, M., Nintanda, T., Kadota, N., Otha, H., Suetsuna, K. and Osajima, Y. (1984) Adsorption of satsuma mandarin juice aroma on plastic films. *J. Jpn. Soc. Food Sci. Technol.*, **31**, 67.

Shorten, D.W. (1982) Polyolefins for food packaging. *Food Chem.*, **8**, 109.

Sizer, C.E., Waugh, P.L., Edstam, S. and Ackermann, P. (1988) Maintaining flavor and nutrient quality of aseptic orange juice. *Food Technol.*, **42**, 429.

Smith, J.P., Ramaswamy, H.S. and Simpson, B.K. (1990a) Development in food packaging technology. Part 1: processing/cooking considerations. *Trends Food Sci. Technol.*, **Nov**, 107.

Smith, J.P., Ramaswamy, H.S. and Simpson, B.K. (1990b) Developments in food packaging technology. Part 2: storage aspects. *Trends Food Sci. Technol.*, **Nov**., 111.

Sneller, J.A. (1986) Smart films give a big lift to controlled atmospheric packaging. *Modern Plastics*, **August**, 58.

Subramanian, P.M. (1990) Polymer blends – Morphology and solvent barriers, in *Barrier Polymers and Structures* (ed. W.J. Koros), ACS Symposium Series 423, Washington DC.

Takahashi, J., Yuda, S. and Yanagslawa, H. (1984) Oxygen scavenger systems. *Japan Food Packaging*, **28**, 40.

Turtle, I. (1987) The use of flexible plastics for food packaging. *Food Technology International Europe*, Sterling Publications, London, pp. 289–96.

Wolpert, V.M. (1987) Oxygen scavenging for extended shelf life. *Paper, Film and Converter*, **12**.

Yamada, K., Mita, K., Yoshida, K. and Ishitani, T. (1992) A study of the absorption of fruit juice volatiles by the sealant layer in flexible packaging containers (The effect of package on quality of fruit juice, part 4). *Packaging Technol. Sci.*, **5**, 41.

Yokoyama, T. (1992) Food packaging overview. *Packag. Japan*, **13** (68), 25.

Yoshii, J. (1990) Smokable casing Krehalon, 'SMO Casing'. *Packag. Japan*, **11**(55), 35.

Yoshii, J. (1992) Recent trends in food packaging development in consideration of environment. *Packag. Japan*, **13**(67), 74.

Zagory, D. and Kader, A.A. (1988) Modified atmosphere packaging of fresh produce. *Food Technol.*, **42**(9), 70.

5 Preservation technology and shelf life of fish and fish products

D.M. GIBSON

5.1 Introduction

The food matrix has a positive rather than simply a passive role in preservation methods because it interacts with the microbial flora responsible for its deterioration and can moderate by compartmentalisation within its structure the chemical, biochemical and physical changes which take place during storage.

Fish and fish products will be used here as examples of past, current and proposed technologies for food preservation and for methods to assess their effectiveness. Most technologies have been applied to try to reduce the perishability of fish and hence increase the short shelf life. It is a worldwide resource with a current yield of about 100 million tonnes per annum. Utilising this resource tests food technologies to their limit. Harvesting is unpredictable; catches may yield gluts or there may be shortages. The species mix, the size mix, the intrinsic condition of fish are all uncontrollable, yet the products have to compete in sophisticated international markets, as well as meet local needs. Farmed fish is an increasing resource; husbandry techniques are still evolving and there are considerable problems of losses caused by diseases to the stock, by escape to the environment, and by predators such as birds and sea mammals. As many farms are located in regions remote from the processing factories and markets, the logistics of supply are not simple. Fish is sold as whole fish or fillets, fresh or frozen, smoked, dried, salted, fermented, marinaded, as added value products, and in recipe dishes mixed with other ingredients. These products may only have been available in restaurants a few years ago, that is, prepared for immediate consumption, but now are sold in supermarkets and given substantial shelf lives.

Food poisoning consequent to the consumption of fish is relatively rare, except in countries where much fish is consumed raw. Thus, fish is implicated in 2% of food linked diseases in the UK, but in 11% of outbreaks in the USA, 20% of those in Australia, and 70% in Japan. Illness is attributed to bacteria, their toxins, viruses, algal toxins, parasites, and to heavy metal ions. Shelf life can be limited by spoilage or by safety considerations. Fisheries can be closed either temporarily as in the case of

algal blooms or permanently where pollution, for example, by mercuric or cadmium ions, has been detected.

This chapter describes, in an illustrative manner, the technologies which are or could be applied to fish and fish products and their effects on the shelf life of the products. Despite the diversity of the resource there is a remarkable uniformity in the effects of applied technologies. Indeed, the same principles and considerations can easily be applied to other foods.

5.2 Properties and spoilage of fish

Fish are cold blooded aquatic vertebrates broadly classified as bony such as cod, salmon, and herring or cartilaginous such as the skates, rays and sharks. Their sizes range from a few centimeters to meters, and their shapes from round to flat. The edible tissue is about 50% of the live weight. Some of the remainder is used, for example oils are extracted from the livers, but most is discarded. It can be converted to animal feed or fertiliser in the form of fish meal or silage. The edible portion is mainly muscle which is arranged in conical structures. During life, this flesh is sterile, protected by the skin through which antimicrobial compounds, such as lysozyme, are secreted, and by antibodies in the blood.

Regarding composition, fish are classified as lean, being 20% protein, $<5\%$ lipid, with little carbohydrate, or fatty with 10–30% lipid. Their lipid content varies with season or availability of food. When the lipid content is high, the water content is low, as the sum of lipid plus water is usually 80%. The low molecular weight pool represents 1–3% by weight and is significant for shelf life, being the readily available nutrients for bacteria. The pH of the flesh is near neutral. It is highly buffered, due to the protein content, phosphates, and creatine, a muscle constituent. The oxidation–reduction potential during life is relatively low due to the environment.

The intrinsic condition of fish, that is the biological condition on harvesting or capture, varies with season depending on spawning and migratory cycles, and with method of fishing, as exhausted fish may be in poor condition or damaged. Also, large catches cannot be handled sufficiently quickly.

As with all forms of life, harvesting causes death which is characterised by a cessation of the supply of energy to the organism. During life, food is consumed, digested to small molecules, some of which are used as carbon and nitrogen sources for the biosynthesis of macromolecules and tissues, and others to provide energy for this. Tissue turnover also occurs. On death of the animal, food supply ceases as does the supply of energy, but turnover of molecules can continue. Energy reserves are used up and so the natural integrity and defences of the animal deteriorate. For

example, cell membranes are no longer energised and molecules and ions can freely diffuse; antimicrobials are no longer produced nor distributed. Bacteria which have been kept on the outside surfaces (skin, intestines, gills) by secretions, can penetrate the skin and flesh. The purely biochemical and chemical changes in the tissue cannot be arrested by the application of preservation technologies, only slowed by temperature effects on their kinetics, except by drastically altering the material, as for example by cooking. Technologies can have effects on the activities of bacteria. It has been shown for many foods that biochemical changes which may reduce their desirability as foods do not cause sufficient changes such that they are regarded as spoiled. It is the effects of bacteria found on the raw materials or in the environment in which they are processed, that cause the sensory changes resulting in spoilage. Within the microflora, it is recognised that only a proportion of the bacterial types present is responsible for producing the off-odours, flavours, appearance and textural changes which constitute spoiled fish.

How can spoilage be characterised and measured? Systematic studies by technologists have resulted in quality assessment schemes which are used by industry and by regulators. The changing sensory features have been described in detail for many species and an example is given in Table 5.1. For non-destructive testing, the odour of the gills has been considered the

Table 5.1 Score sheet for sensory changes of white fish

Raw Quality	Score	Gill odour	General appearance
Fresh	10	Seaweed, sharp metallic	Convex eyes, shiny red blood, flesh translucent
Spoiling	7	Bland, loss of tanginess	Eyes flat, dull skin, no translucence
Stale	5	Milky, mousy, yeasty	Sunken eyes, browning of gills, opaque mucus, waxy flesh
Putrid	3	Acetic acid, 'old boots', sour sink	Eyes very sunken, yellowing flesh, brown blood, yellow bacterial slime
Cooked Quality	**Score**	**Odour/flavour**	**Texture**
Fresh	10	Slight sweet/meaty	Dry
Spoiling	7	Bland/neutral	Firm/succulent
Stale	5	Some amines, 'off'	Softening
Putrid	3	Bitter, sulphides	Mushy

most reliable and reproducible. The cooked flavour of fish portions, steamed or microwaved without added condiments, is the most precise. Tasting requires a group or panel of people to reduce individual bias. Scoring systems have been devised. Flavour, odour and appearance descriptions are agreed by the panel, the actual words having little true meaning, being memory aids, and scores given such that there is a linear relationship between the change in score with storage time at a constant temperature. It is evident from Table 5.1 that sensory characteristics such as flavour have more distinct stages than others such as appearance and texture.

The organoleptic changes are caused by bacteria. In fish taken from temperate marine waters, the active bacteria are psychrotrophic or cold loving, well adapted to growth under chill conditions. They have one particular property which results in the high perishability or short shelf life of fish products. Marine fish contain trimethylamine oxide (TMAO), as an osmoregulator. Some bacteria can reduce this to trimethylamine which has the odour of stale fish. The bacteria can obtain energy from this reaction and use it as electron acceptor in the absence of oxygen. The system is similar to nitrate reduction and shares some components. Fresh water fish contain little TMAO and generally have a longer shelf life. The technologies for marine fish preservation are essentially those which reduce or eliminate the activities of the TMAO-reducing bacteria. There is little fermentation activity in the microflora, a well recognised source of energy in other foods. This is because of the low carbohydrate content of most fish. The concentration of TMA has been used as an index of spoilage either alone or as a component of 'total volatile bases', which includes ammonia and other amines. These have proved useful in research in comparative trials but less so in commerce due in part to batch to batch variability. In addition, because bacterial numbers show a lag (Figure 5.1) before increasing, chemical indices of bacterial activity are insensitive to changes in very fresh fish. Setting limits or standards for the permitted concentrations of such volatiles can be a problem with packaged fish where they accumulate to higher levels than in unpackaged fish for the same organoleptic quality because they can no longer vaporise and escape. An alternative chemical index is hypoxanthine, derived from the breakdown of adenosine triphosphate (ATP). This accumulates from the death of the fish and is applicable to marine and fresh water species. It shows some species variation to the differing concentrations of ATP during life. A more complex measurement is the '*K*' value, based on ATP, adenosine diphosphate (ADP), adenosine monophosphate (AMP) and hypoxanthine. 'Total volatile bases' concentration and nucleotide metabolites are used as indices for other proteinaceous foods. Lipid oxidation can be measured by standard techniques such as malonaldehyde content or by HPLC methods but these are not generally used outside the research laboratory.

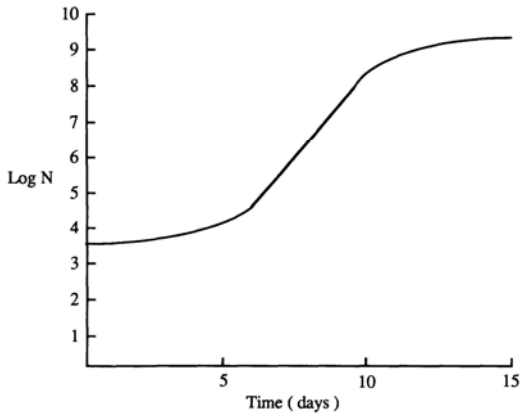


Figure 5.1 Changes in the number (N) of bacteria on fish stored at 0°C.

Storage trials and tests are usually done on products stored under the temperature conditions anticipated in industry. Accelerated tests done at higher temperatures are of little value for shelf life determination of fish as the developing microflora may differ and the pattern of spoilage may alter. Challenge testing for pathogen growth and survival, however, can be done in that way.

Spoilage results in changes in the electrical properties of the skin and tissue, due in part to membranes no longer being energised. Changes in the dielectric properties of whole fish and of skin-on portions can be made in an instant non-destructive manner using a handheld device such as a Torry Fish Freshness Meter (Figure 5.2). The measurements obtained relate more to an estimation of the remaining shelf life than to the lapsed shelf life. These instruments are used in some countries for sorting fish.

5.3 Conventionally preserved fish and fish products

Except for artisanal fisheries for purely local markets, most fish are chilled soon after capture with ice. They may be gutted, that is, have their intestines removed. For some species this is essential as otherwise the digestive enzymes and the bacteria in the gut would soon attack the flesh, although in others this may not be necessary due to the anatomical location of the gut cavity relative to the edible parts. In some fisheries, it is customary to wash the fish, to remove blood, remnants of guts and so on. However, washing can remove some of the natural antimicrobial secretions and may not be advantageous to the storage life. The importance of rapid chilling cannot be overstressed. Chilling reduces the rates of chemical and biochemical reactions. Microbial growth is slowed or even stopped. However,



Figure 5.2 Torry Fish Freshness Meter in operation on cod boxed in ice.

because the temperature at which the fish live is, in many parts of the world, relatively low, chilling of fish does not have such a large effect as the chilling of meat from warm blooded animals. Ice is a very good coolant. It is also cheap; it must be made from pure, unpolluted and bacteria free water. It has a large heat absorbing capacity due to the latent heat of ice–water transition, and the melt water provides excellent contact with the fish. It is essential that this water can drain as fish spoil rapidly in stagnant water. Chilling reduces the temperature of fish to 0°C. If the temperature is reduced further, the effect on bacterial growth is greater. Marine fish do not freeze until –3°C. 'Superchilling' is being developed for other foods. Its usefulness depends on avoiding slow freezing or freeze–thaw cycles as this has a deleterious effect on the appearance and texture of the products. Chilled environments become colonised with a microflora well adapted for the conditions. Good hygienic practices are needed to reduce the possibility of contamination of products. This is achievable on land but is more difficult on board fishing vessels. Fish may spend 2 weeks stored at sea.

Freezing of fish, at sea or on land, is a well established technology. When frozen, bacterial growth ceases, however, chemical and biochemical reactions, including those carried out by microbial enzymes, can continue. During freezing, the formation of ice crystals results in a concentrated solution of substrates and enzymes. Rapid freezing is essential so that this

'soup' is inactivated as soon as possible. Not all the water is frozen even at −20°C. The main deteriorative effects on eating quality are toughening due to protein denaturation, more prominent at high (−10°C) and fluctuating temperatures, and rancidity due to lipid oxidation. Exclusion of oxygen, by suitable packaging or glazing, reduces this. Due to their high proportion of unsaturated fatty acid residues, fish lipids are particularly susceptible to oxidation. These non-microbial changes can reduce the future processability of the products and their consumer desirability. The temperature of storage for lean fish should be better than −20°C, for small fatty fish −30°C, and for large fatty fish such as tuna, −70°C. Freezing does not have a significant effect on killing bacteria on and in foods. Frozen and then thawed foods have similar bacterial numbers to the starting material. There may be an increase in the lag period before growth due to the thermal injury, but the damage to the food matrix probably allows easier access of the bacteria to their potential nutrients.

Smoking fish is a traditional method of preservation, done nowadays more for flavour than for long term preservation. The process consists in lightly salting the fish, smoking in a kiln at either low or high temperature, with simultaneous drying. The salting, done either by sprinkling dry salt on the surface or by immersion in strong salt solutions (brining) serves to inhibit the spoilage flora. The smoke vapours impart flavours to the product but are also inhibitory to bacteria due to their content of aldehydes, organic acids, and phenols. Some drying also occurs. Cold smoking, at temperatures of 25°C, yields products with perhaps twice the shelf life of the raw material. The normal spoilage flora is partially inhibited and spoilage is initiated by yeast and moulds which are found in the wood shavings and sawdust used to generate the smoke. Final spoilage may be caused by bacteria which are no longer inhibited as the smoke components vaporise. These products generally require cooking before consumption. In hot smoking, temperatures >60°C are reached and so the product is well pasteurised and cooked. Significant drying especially of the surface occurs. Spoilage, as characterised by amines or other off-odours, may take months to be noticeable.

Traditionally, fish have been heavily salted (salt content $>25\%$), and/or dried to a water content of $<25\%$. The microflora is inhibited by low water activity. Strictly speaking, the water activity is a concept which requires equilibrium conditions to be established. These high salt–low water conditions inhibit the normal flora. Spoilage can occur due to the activities of halophilic pink bacteria or some brown xerophilic moulds ('dun'), both originating in the salt. These products have a shelf life of years provided that they are protected from taking up moisture. They can only be produced in areas of low humidity; otherwise mechanical drying systems are needed.

Lowering the pH by fermentation or by the addition of organic acids

such as vinegar (acetic acid) is another traditional method of fish preservation. The spoilage flora is active in the pH range 5.5–8.5, and TMAO reduction in the pH range 6.0–8.0. For safety reasons (see section 5.5), the pH of acidified products should be <pH 4.5. Because of the high buffering capacity of fish tissue and low carbohydrate content of fish flesh, fermentative microbes require the addition of sugars, to be effective. Many fermented fish sauces are produced in the Orient. Marinaded products are popular in some countries. Many additives such as herbs and spices are added to enhance flavours. In Finland, a fish product, gefilde fish, is made by raising the pH with alkali. This is an acquired taste, the soapy flavour being unique.

Adequate thermal processing is another example of preservation used with fish. This kills microbes and yields a stable product. A well established method of thermal processing is canning. Salmon, tuna, sardines and pilchards are well known examples of canned fish. Because of the risk of botulism (section 5.5), a full heat treatment (121°C, 15 min.) is required. Thus only strongly flavoured species such as those listed are canned. Others such as cod and sole develop undesirable characteristic flavours. Breakup of structure and texture also limit the applicability of canning.

Waste fish and excessive supplies of fish can be reduced to fish meal. The raw material is cooked and then dried. High quality fish meals or flours extracted from them have been used directly for human consumption. Lesser heat treatments are described in the following section.

5.4 Modern technologies

Probably the greatest change in the marketing of fish in recent years has been the use of flexible packaging materials for chilled products. Prepackaged fish dominates sales in some countries, especially where traditional fishmongers have lost out due to city centre redevelopments. Packaging does not improve the quality of fish, only its presentation. The rate of spoilage and therefore the shelf life of packaged and unwrapped fish is generally similar. Extensions to shelf life claimed for certain types of packaging depend on the definition of the quality level at the end of shelf life. The end of shelf life is generally expressed in terms of taste panel score. Public health authorities use a low score, equivalent to gill odour or cooked flavour of 4.5 (see Table 5.1). At this stage, fish products have a strong stale or putrid odour. Supermarket technologists reject fish at a higher score, equivalent to 5.5 or 6.0. At this stage the product is stale. Much of the claimed extension to shelf life due to packaging systems occurs in this last region, spoilage being the same until staleness is evident but at a slower rate in the stale to putrid stage. For some products and

for some markets this may well be acceptable, but in many instances, the quality is poorer than the retailer would wish. The main determinants of quality for packaged fish are the storage temperature and time. Vacuum packaging and modified atmosphere packaging have a role in the presentation of fish products, and in arresting rancidity changes, but not in maintaining high quality shelf life. On the other hand, if there is accidental temperature abuse, then the product would be less offensive for longer.

Pasteurisation of fish products can be done with heat or irradiation. There is a growing market for 'sous vide' products. These are partially cooked and require only reheating before consumption. The raw materials are vacuum packed and then heat treated. Fish cooks so quickly that the thermal process may be completed in a few minutes at 65–70°C. The normal spoilage flora is destroyed so that such products do not develop characteristic odours during storage. As the heat treatment is insufficient to destroy the spores of *C. botulinum* (section 5.5), limits must be set on the maximum time and temperature of storage.

Irradiation from cobalt-60 or other electron sources has been fully investigated. The process is bactericidal but the limiting factor is the development of off-odours and flavours caused by the process. These are described as being like burnt hair or feathers and are due to reactions of thiol groups. Sterilisation is therefore not practical. Pasteurisation, equivalent to a 3D process, that is reduction of the microbial load by a factor of 1000, is feasible and done in some countries yielding products with no appreciable irradiation odours. To be effective for shelf life extension, only fresh fish should be used. The spoilage flora is reduced, especially the bacteria able to reduce TMAO, and shelf lives similar to those obtainable with meat are possible. To prevent recontamination, products are packed. There is an effect on the appearance, in that juice or drip is released from the fish. There are no unequivocal tests for detecting irradiated fish. There is no improvement in the quality of the product due to the process so there is no possibility of poor quality spoiled fish being converted to good quality. However, there are said to be instances of poor quality fish having unexpectedly low bacterial counts.

There has been a huge increase in the amount of farmed fish being marketed worldwide. In temperate zones, the main species have been salmon and trout for which markets have had to be created. These species are sold in various retail forms, usually packed, as steaks, fillets, and especially smoked. Cold smoked salmon and hot smoked trout are sold vacuum packaged. Compared with wild caught fish, they have a comparatively long shelf life because the time between harvesting and processing is short, harvesting can be done according to demand, and much processing is done under contract. The shelf life limits are safety rather than quality related. Internationally, there are plans to transport farmed fish under

Table 5.2 Approximate shelf lives of various products

Product	Temperature (°C)	Shelf life (days)
Cod (raw)	0	16
	5	7
	10	4
	16	1
Herring (raw)	0	10
	5	4
Salmon (raw)	0	20
	10	5
Plaice (raw)	0	18
	10	8
Cod (smoked)	5	14
Kipper (smoked herring)	5	10
Salmon (smoked)	5	20
Cod (sous vide)	0	28
Cod (irradiated)	0	20
Cod (salted)	0	500
Herring (marinated)	5	100
Beef	0	40
Chicken	0	14
Bacon	5	21

controlled atmospheres. Probably, the close control of temperature in such systems will be more important than the gas mixture used, except perhaps for colour retention. Table 5.2. gives a summary of approximate shelf lives of various products achievable by different preservation technologies.

5.5 Sensory quality and safety

Sensory assessment schemes for fish have been referred to in section 5.2. Such scoring systems have been derived in research laboratories for research purposes, for example, to compare the technological quality of two treatments of fish. Consumer based quality testing, though not so well developed, is becoming more widely used. In extensive trials with cooked fish samples it was apparent that, in controlled triangular tests, many assessors had difficulty identifying the type of fish being presented let alone commenting on the quality. Preferences were found for all qualities of fish, and a significant proportion of assessors did not like fresh, technologically best quality, fish products. However, consumers do not generally like to meet strong ammoniacal or sulphydryl odours on opening packs.

Accordingly, with fresh fish, the comments on shelf life extensions

based on the selection of cut off organoleptic scores (section 5.2) are technologically rather than consumer based, but represent the strategy adopted by many major retailers.

Fish and fish products generally have a good record with regard to safety to the consumer; shellfish, some of which are eaten raw, cause many cases of food poisoning. The main safety considerations relate to botulism, vibriosis, histamine intoxication, algal toxins, and to a lesser extent, parasites and heavy metal ions. Presence of *Listeria monocytogenes* causes problems in commerce.

All aquatic environments can harbour spores of *Clostridium botulinum* which can contaminate fish, both in marine and fresh water environments. Numbers of cases per annum worldwide are low, but because of the seriousness of the effects of the toxins, technologies are implemented such that there is no increase in the risk of botulism. The organisms can be classified into two groups: the proteolytic strains which develop foul odours, and the non-proteolytic types which are covert in their action. The former do not grow below 10°C, but the latter can grow and produce toxin at temperatures above 3.3°C. Their toxins are heat labile, being easily destroyed during normal cooking. There is no way that the raw material – newly harvested fish – can be made free of the risk of botulism. With fish stored raw, spoilage precedes toxicity such that the products would not be consumed. Although the organism can grow at chill temperatures, the spoilage flora can grow faster. With semiprocessed products, where spoilage flora is removed or inhibited, the risk of botulism is higher, but it should be stressed that most of the recorded cases of human botulism related to fish consumption have been traced to products prepared domestically rather than in industry. Smoked products should be made with a salt content (in the water phase) of $>3.5\%$ NaCl, which is inhibitory to botulinum strains below 10°C. Marinated products should have a pH <4.5. Hot smoked products which are consumed without cooking should have reached an internal temperature >70°C, or according to a recent UK government report, >90°C. If not one of these conditions of salt content, pH, or temperature treatment is met, the report recommends that the maximum shelf life be 10 days, assuming a storage temperature <10°C. Clearly, these conditions mean that the shelf life is based on safety, and the shelf life extensions given by various technologies are lost. The recommendations apply to packaged (vacuum, modified atmosphere), and to 'sous vide' products.

Vibrio parahaemolyticus is the leading cause of food poisoning in Japan where much fish is eaten raw.The organism is present on fish when landed but, as the infectious dose is high, there has to be some temperature abuse to allow for growth. It does not grow below 10°C, dies out at chill temperatures, and is heat labile. As it is halophilic, it survives salting and thus smoking. Control is therefore by proper chill storage.

Histamine poisoning or scombrotoxicity is associated with the consumption of scombroids such as tuna and mackerel. It is a mild illness of short duration but the symptoms can be alarming to the victim. The histamine arises from histidine which is found in high concentration in the fish muscle. The decarboxylation is carried out by enteric bacteria, which do not grow below 10°C. As histamine is heat stable, it survives all smoking procedures which may kill the producing bacteria. Control is carried out by specifying the absence of histamine in raw materials followed by chill temperature control.

There is a global increase in the presence of algal toxins in shellfish, for unknown reasons. More toxins are being identified. There are now over 20 saxotoxin derivatives, which cause paralytic shellfish poisoning, ten diarrhetic poisons, some neurotoxins, and some which cause loss of memory. Shellfisheries are regulated by monitoring schemes to reduce any risk to the consumer so that toxic products should not enter the food supply. There is some evidence, however, that some toxins may move up the food chain, by for example fish eating shellfish, and there are reports that some outbreaks of scombrotoxicity, where little histamine has been found in the food consumed, may be due to algal toxins. There is no production of such toxins during storage of fish or shellfish.

The major concern in recent years to the fish processing industry has been with *Listeria monocytogenes*. There have been few authenticated cases of human listeriosis associated with the consumption of fish or fish products, but there are some due to shellfish. In many surveys, *Listeria* has been detected in 20% of samples, normally at <1 cell per gram. As many specifications for food include the virtual absence of *L. monocytogenes*, this can cause problems for food manufacturers. In addition, the organism can grow at chill temperatures and is not inhibited by the levels of salt in smoked products. Shelf life can thus be limited by the shelf life predicted by modelling given the storage temperature profile. Smoked salmon is the product most affected in trade as it is cold smoked and eaten without further cooking, but it must be stressed that no outbreaks of the disease have been traced to this product.

5.6 Conclusions

As fish products have moved from specialist processors and independent retailers into the mainline food industry and supermarkets, and as supplies have become global rather than just local, it would be unusual if there were no problems relating to quality or safety. Technologists have assessed the effects of each innovation and have produced codes of practice which have been apparently successful in providing the consumer with desirable and safe products for which the demand grows. With the

knowledge and data base already acquired, there is no reason to believe that the industry will not continue to grow and thrive, provided that adequate respect is shown to the technology and to realistic shelf lives.

Bibliography

Anon (1991) A workshop – Behaviour of gram-negative pathogens on refrigerated foods. *Int. J. Food Microbiol.*, **13**, 183–238.

Baker, D.A. and Genigeorgis, C. (1990) Predicting the safe storage of fresh fish under modified atmospheres with respect to *Clostridium botulinum* toxigenesis by modeling length of the lag phase of growth. *J. Food Protection*, **53**, 131–40.

Bligh, E.G. (1992) *Seafood Science and Technology*, Fishing News, Oxford.

Conner, D.E., Scott, V.N., Bernard, D.T. and Kautter, D.A. (1990) Potential *Clostridium botulinum* hazards associated with extended shelf-life refrigerated foods: a review. *J. Food Safety*, **10**, 131–53.

Eyles, M.J. (1986) Microbiological hazards associated with fish products. *CSIRO Food Res. Q.*, **46**, 8–16.

Farber, J.M. (1991) Microbiological aspects of modified-atmosphere packaging technology – a review. *J. Food Protection*, **54**, 58–70.

Farber, J.M. (1993) Current research on *Listeria monocytogenes* in foods: an overview. *J. Food Protection*, **56**, 640–3.

Gould, G.W. (ed.) (1989) *Mechanisms of Action of Food Preservation Procedures*. Elsevier Applied Science, London.

Harrigan, W.F. and Park, R.W.A. (1991) *Making Safe Food*, Academic Press, London.

Huss, H.H., Jakobsen, M. and Liston, J. (eds) (1992) *Quality Assurance in the Fish Industry. Developments in Food Science*, **30**, Elsevier, Amsterdam.

Kramer, D.E. and Liston, J. (eds) (1987) *Seafood Quality Determination. Developments in Food Science*, **15**, Elsevier, Amsterdam.

Lambert, A.D., Smith, J.P. and Dodds, K.L. (1991) Shelf life extension and microbiological safety of fresh meat – a review. *Food Microbiol.*, **8**, 267–97.

Parry, R.T. (1992) *Principles and Applications of Modified Atmosphere Packaging of Foods*, Blackie Academic & Professional, Glasgow.

Part 2 – The practice

6 Delicatessen salads and chilled prepared fruit and vegetable products

T.F. BROCKLEHURST

6.1 Introduction

Delicatessen salads and prepared fruit and vegetables represent groups of short shelf life products that have shown considerable and steady market growth over the past decade (Young, 1984; Hilliam, 1986; Horne, 1989).

Delicatessen salads can be defined here as products that contain chopped, shredded, or entire cooked or raw vegetable or fruit tissue with or without inclusions of animal origin and contained in a dressing, which is most frequently either mayonnaise or vinaigrette. Mayonnaise is an oil-in-water emulsion, whereas a vinaigrette is a dressing also made from oil and an aqueous phase, but it is usually not emulsified. The pH of products in mayonnaise dressing is normally within the range of 3.2–5.1, in vinaigrette dressing 3.7–4.0, and in other dressings 4.0–5.7 (Rose, 1984), although the pH of some products can be as high as 6.6 (Pace, 1975; Terry and Overcast 1976). Examples of such salads include potato salad, Florida salad, vegetable salad and coleslaw and its variants. On the supermarket shelf the products are usually packaged in plastics tubs, and large buckets of salad are sold by some manufacturers for institutional catering.

Prepared fruit and vegetables, on the other hand, do not have a dressing, and examples range from single commodity packs of ready-to-eat washed, sliced, chopped or shredded prepared vegetables or fruits, and 'dry' coleslaw mixes, to complex mixed salads and stir-fry products. Ready-to-use prepared fruit and vegetable products are a popular range in France where they are known as 'Légumes de 4ème Gamme'. The predominant market for these attractive and colourful products is the supermarket shelf and packing for this sector is usually on expanded polystyrene or PVC trays overwrapped with a stretch film of plasticised PVC (Figure 6.1), or in a vertical form-fill-seal 'pillow-pack' made from oriented polypropylene (Figure 6.2). Some prepared vegetables are available in catering packs, which are often made from laminates containing low density polyethylene and are sometimes vacuum packed.

All of the products discussed here are highly perishable and subject to deterioration caused by biochemical, physical and microbiological changes



Figure 6.1 Chilled prepared fruit and vegetable products packaged in trays overwrapped with a PVC cling film.

occurring within them during shelf life. Chilled storage is a major factor in the stability of all of this diverse range of products, and research workers and producers alike repeatedly state that storage at low temperatures can retard the deteriorative changes that limit shelf life. The Institute of Food Science and Technology recommend a storage temperature of 0–5°C for dressed salads of pH 5.0 or above and prepared salads without a dressing (IFST, 1990), and a storage temperature of either 5°C or 8°C (depending upon the composition of the food) was stipulated for chilled foods in the UK Food Hygiene (Amendment) Regulations 1990 (Anon, 1990). Even within this temperature range, however, the shelf life obtainable in the case of prepared un-dressed products is only a matter of a few days: delicatessen salads marketed in a dressing contain additional preservation factors and their shelf life tends to be longer. The temperature dependence of changes that determined shelf life in salads with and without dressings was shown by Williams (1990) to follow a square root relationship, which can be used for predictive purposes.

It is vital that only ingredients of the highest quality are used in the production of delicatessen salads and chilled prepared fruit and vegetables, and that suitable precautions are taken to ensure the absence of



Figure 6.2 Prepared salads in vertical form-fill-seal 'pillow packs' made from oriented polypropylene.

pathogenic microorganisms, which may be part of their naturally associated microflora (Roberts, 1990). Removal of damaged or dirty areas of vegetables or fruits should be the first step in their preparation, for this can decrease the numbers of microorganisms associated with them (Adams *et al.*, 1989). Washing or dip procedures are adopted by manufacturers to decrease the numbers of microorganisms still further. These treatments are usually based on proprietary washing agents and the accumulated experience of the producer. Much research has been directed towards improving washing treatments, and in the choice of washing agents, but an effective decrease in the numbers of viable microorganisms associated with cut vegetable or fruit tissues, or inhibition of their growth during prolonged storage of the product is difficult to achieve (Shapiro and Holder, 1960; Priepke *et al.*, 1976; Bolin *et al.*, 1977; Nguyen-The and Prunier, 1989). Some washing agents have deleterious effects on flavour, texture or appearance (Huxsoll and Bolin, 1989).

Garg *et al.* (1990) investigated the use of chlorine dips in a processing factory. They found that the numbers of viable bacteria were not always decreased by the dip procedure and that their target concentration of free chlorine of 300 mg l^{-1} was not always attainable, probably a result of the reaction of the chlorine with the tissues being treated.

Adams *et al.* (1989) showed that washing cut lettuce tissue in chlorinated water removed 97.8% of the microorganisms, which was little better than the use of tap water, but acidification of the chlorinated water improved the decrease in the numbers of viable microorganisms.

Addition of a surfactant to washing water decreased the numbers of microorganisms to a greater extent than a treatment without surfactant. Although this can introduce taints into the cut tissues, it is an indication that many of the microorganisms on the surface of vegetable tissues may be protected in areas that are difficult to wet in normal washing processes (Adams *et al.*, 1989).

Additionally, dips to prevent organoleptic deterioration of cut vegetables or fruits either to be marketed 'dry' or as components of coleslaw have been suggested (Kaufman and Lutz, 1954; Chen and Peng, 1980). Some (such as ascorbic acid) have been used successfully for the retardation of discoloration (O'Bierne and Ballantyne, 1987; King and Bolin, 1989; Bolin and Huxsoll, 1991), while complex mixtures are also available (Dziezak, 1988), and others (such as sulphites) have associated toxicological hazards and have been banned in some countries. Calcium dips can maintain the firmness of tissues by reacting with the pectic substances in the middle lamella (King and Bolin, 1989). Many manufacturers, however, prefer not to compromise the 'fresh' image of their products with the use of such chemical treatments, while any 'further use' of products so treated must also be considered. For example, surface discoloration of chilled peeled potato strips was prevented by solutions of ascorbic acid, but when these strips were fried their colour was poor (O'Bierne and Ballantyne, 1987).

6.2 The products – their characteristics

All of the products within this grouping are complex processed foods. A high proportion of the product is usually shredded, chopped or diced. The characteristics of these processed vegetable or fruit tissues differ considerably from those of their entire counterparts. In addition, the dressings of delicatessen salads also undergo interactions with the solid ingredients of the products; such interactions may influence the composition of the dressing quite markedly and affect salad shelf life.

Although some of the ingredients in these products may have been cooked or canned prior to inclusion (Brocklehurst and Lund, 1984) most of the vegetable and fruit components are living tissues. Accordingly, they retain enzyme activity and may remain contaminated with microorganisms. Both of these characteristics can contribute to a reduction in quality or shelf life.

The number of products within the product range is enormous and increases almost daily. It is unnecessary, however, to consider each product as radically different from others within the range because certain fundamental characteristics can be identified as having considerable effect on their shelf life. All of the products may be considered as being composed of a number of different phases (i.e. solid, aqueous, lipid and gas phases) and the deteriorative changes that can occur during product shelf life are due to interactions between these phases.

In the case of delicatessen salads, the solid phase is the included tissue of vegetable or animal origin; the aqueous phase includes the liquid that exudes from the cut surface of the vegetable or animal tissue and this is continuous with, and effectively indistinguishable from, the aqueous phase of the dressing; the lipid phase is the oil component of the dressing; and the gas phase is the headspace above the salad within the packaging.

In mayonnaise-based delicatessen salads the solid ingredients may constitute between 50% and 75% (w/w) of the product. The oil in mayonnaise (typically between 29% and 76% (w/w), though the more recent 'diet' dressings contain much less oil than this) in present as dispersed droplets with a mean droplet diameter of about 5 μm (Tunaley *et al.*, 1985; Ranken, 1988). Other ingredients in the mayonnaise usually include vinegar, sugars, sodium chloride, egg yolk solids (as emulsifier), stabilisers (such as guar, tragacanth or xanthan gums) and additional minor ingredients like mustard powder, lactic acid, colourings, or preservatives such as sorbic acid or benzoic acid (Brocklehurst and Lund, 1984).

In the case of prepared fruit and vegetables, the solid phase is the fruit or vegetable tissue; the aqueous phase is confined to the exudate that is released from the cut surface of the tissues; and the gas phase usually constitutes a large volume within the pack, is in contact with most of the surfaces of the vegetable or fruit components, and its composition may be modified deliberately at the time of packing.

Whereas most of the major changes that limit shelf life can be explained by reference to interactions between the phases described here, it is also true that certain minor components of delicatessen salads exhibit changes during shelf life that are unique to those ingredients (Geeson *et al.*, 1987).

6.3 Specific factors affecting shelf life

The shelf life of delicatessen salads and prepared fruit and vegetable products is influenced very strongly by changes that occur during storage and that, if allowed to continue unabated, would lead to microbiological or organoleptic spoilage.

6.3.1 Delicatessen salads

The characteristics of the mayonnaise or vinaigrette dressing have considerable influence on the shelf life of these products. The object of the manufacturing process should be to produce a product in which the solid ingredients are intimately associated with the dressing, which should be specifically formulated in order to confer some organoleptic and microbiological stability on the solid ingredients. A knowledge of the interactions that occur between the phases of the dressings and the dressing and the solid ingredients of the food, therefore, is fundamental to an understanding of the factors that limit shelf life.

6.3.1.1 Interactions between phases

(a) Behaviour of organic acid preservatives in the aqueous phase. The aqueous phase of the dressing contains chemical components that confer organoleptic quality to the dressing, but that also increase the safe shelf life of the salads by killing, or retarding the growth of, microorganisms. These components may be in the form of traditional ingredients of the dressing, such as acetic acid, lactic acid, sodium chloride and sucrose, or preservatives (such as sorbic acid or benzoic acid) added deliberately to extend shelf life. The organic acids are the most potent antimicrobial agents in the dressings, but the concentration of sodium chloride and sugars can increase the microbiological stability (Tuynenburg Muys, 1971). Their influence is included in the CIMSCEE (1985) equations, but the concentration of these components in dressings is usually quite low (Brocklehurst and Lund, 1984) and alone is insufficient to prevent the growth of microorganisms (Lueck, 1980). In any case, the concentration of sodium chloride and sucrose decreases markedly by dilution when the dressing is mixed with the solid ingredients of the salad, as discussed later.

In the preservation of delicatessen salads, it is the concentration of organic acids, then, that is most important and a chemical characteristic that affects their efficacy as antimicrobial agents is that of dissociation. This is the property of a molecule to separate into specific component parts, and in the case of organic acid food preservatives this occurs by an ionisation reaction. The general reaction for dissociation is:

$$RH \leftrightharpoons R^- + H^+ \tag{6.1}$$

and for acetic acid, for example, this would read:

$$CH_3COOH \overset{K_a}{\rightleftharpoons} CH_3COO^- + H^+ \tag{6.2}$$

undissociated acetic acid — dissociated acetate ion and proton

Table 6.1 Published values for dissociation constants and pK_a values at 25°C for some common organic acids

Organic acid	Dissociation constant[a]	pK_a
Acetic	1.76×10^{-5}	4.76
Lactic	1.37×10^{-4}	3.86
Benzoic	6.46×10^{-5}	4.20
Sorbic	1.73×10^{-5}	4.76

[a]mol l^{-1}

In this case, the dissociation reaches an equilibrium. This is characteristic of a weak acid as it is only partially ionised in aqueous solutions at normal concentrations. The degree of dissociation of an acid is described by a constant, called the dissociation constant (K_a), which is the ratio of the product of the concentrations of the dissociated species to the concentration of the undissociated acid at equilibrium, at a standard temperature. The dissociation constant is characteristic of a particular acid, and in the case of weak acids is a somewhat cumbersome small number (Table 6.1). Its negative logarithm, however, is more easily manipulated, and this is known as the pK_a (Table 6.1). The value of K_a is affected slightly by temperature, and useful equations for determination of this are given by Robinson and Stokes (1959).

Dissociation is important in food preservation because the antimicrobial activity of the undissociated and dissociated species differs and it is the undissociated acid that is the predominantly antimicrobial agent (Baird-Parker, 1980; Eklund, 1983). The site of microbial growth in emulsion dressings is in the aqueous phase (Tuynenburg Muys, 1971) and hence it is the concentration of the undissociated acid in this phase of the dressing that is most pertinent to a shelf life that is microbiologically safe and stable. The concentration of undissociated acid is influenced by the acidity of the food as the following shows:

$$CH_3COOH \underset{\text{decreasing acidity}}{\overset{\text{increasing acidity}}{\rightleftharpoons}} CH_3COO^- + H^+ \qquad (6.3)$$

When the acidity of the food is increased (i.e. the pH is decreased) the concentration of H^+ in the food increases and this influences the above equilibrium (which is still governed by the pK_a), driving equation (6.3) to the left thereby increasing the concentration of the undissociated acid.

The concentration of the undissociated acid is a function, therefore, of the initial concentration of that acid in the food, its dissociation constant and the pH of the food. The concentration of the undissociated acid at a given pH can be calculated by using the Henderson-Hasselbalch equation:

Table 6.2 Calculated effect of pH on the proportion of acetic acid present as the undissociated acid, assuming a pK_a of 4.76.

pH	% undissociated
3.0	98.29
4.0	85.19
4.2	78.41
4.4	69.61
4.5	64.54
4.6	59.11
4.76	50.00
4.8	47.71
5.0	36.52
5.2	26.64
5.4	18.64
5.5	15.40
5.6	12.63
6.0	5.44
7.0	0.57

$$\text{pH} = pK_a + \log_{10} \frac{\left(\begin{array}{c}\text{concn. of dissociated species} \\ \text{i.e. the salt/conjugate base}\end{array}\right)}{(\text{concn. of undissociated acid})} \qquad (6.4)$$

It follows that when the pH of the food is equal to the pK_a of the acid, the concentrations of the undissociated acid and its dissociated species are the same. As the pH falls below the pK_a, the proportion of antimicrobial undissociated acid increases (Table 6.2). Any interaction occurring within these products that changes the pH will, therefore, have a direct influence on the concentration of undissociated acid available as an antimicrobial agent.

(b) Aqueous phase/lipid phase interaction – organic acids. The undissociated organic acids are lipophilic, and hence soluble in the lipid phase of foods, but to varying extent. The relative solubility of these acids in the lipid and aqueous phases is described by their partition coefficients (Table 6.3). The low partition coefficient of acetic acid explains its being used as the predominant antimicrobial agent in these foods, but the high partition coefficients of benzoic acid and sorbic acid, which are sometimes deliberately added as preservatives to multiphase foods, mean that a high proportion of these acids is unavailable as an antimicrobial agent in the continuous aqueous phase.

Clearly, the redistribution of an organic acid preservative through partition affects its concentration in the aqueous phase of the dressing before this is mixed with the salad ingredients as well as being relevant to its final concentration in the same phase in the entire delicatessen salad. The

Table 6.3 Published values for partition coefficients of some common organic acids

Organic acid	Oil:water partition coefficient
Acetic	0.03–0.07
Benzoic	6–13
Sorbic	3.1

Source: Gordon and Reid, 1922; Bodansky, 1928; von Schelhorn, 1964; Leo *et al.*, 1971.

magnitude of the effect is influenced by any change in pH that occurs within the dressing before or after it is mixed with the solid ingredients of the product as this affects the concentration of the undissociated acid.

6.3.1.2 Interactions within the salad. The preparation of a delicatessen salad from its component solid parts and dressing is rapidly followed by many interactions within the product. These involve the redistribution of components between the phases, and, although they are complete within six hours after mixing the salad, these interactions have implications for the sensory and microbiological stability as well as shelf life of the product (Kirsop and Brocklehurst, 1982; Brocklehurst *et al.*, 1983; Brocklehurst, 1984; Brocklehurst and Lund, 1984; Tunaley *et al.*, 1985; Davies and Brocklehurst, 1986). Such interactions can readily be measured and used as the basis of a predictive scheme in order to anticipate the spoilage potential of products with a given compositional profile. Specific interactions follow, and the next sections deal with the ways in which the results of these interactions limit the shelf life of the products.

(a) Solid phase/aqueous phase interaction – moisture. Moisture passes from the vegetable components of the product into the aqueous phase of the dressing (Boyar *et al.*, 1985). The movement of free moisture is in response to the difference in osmotic potential between the vegetable or fruit tissues and the dressing, which is created by the relatively large concentration of solutes in the aqueous phase of dressings. This moisture can represent some 16% of the total moisture that is contained in the vegetable tissue in coleslaw (Davies and Brocklehurst, 1986). The change in volume fraction of the aqueous phase of the dressing caused by the ingress of moisture can be measured directly (Boyar *et al.*, 1985), or the change in oil content per unit volume of dressing can also be used as an indicator (Table 6.4).

The redistribution of water is completed within six hours after mixing the salad. It can result in a loss of turgidity of the vegetable tissue, and one effect of the dilution of the dressing is a marked loss in its viscosity (Table 6.4 and Figure 6.3).

Table 6.4 Oil content and viscosity of mayonnaise before making salads, and of mayonnaise separated from salads six hours after mixing

Salad	Before making salad		Six hours after mixing	
	Oil content (% w/v)	Viscosity (Pas)	Oil content (%w/v)	Viscosity (Pas)
Coleslaw	61	2.54	40	0.32
Florida salad	29	2.03	18	0.36
Potato salad	76	0.69	61	1.38
Vegetable salad	29	2.03	23	1.23
Spanish salad	29	2.03	22	0.80

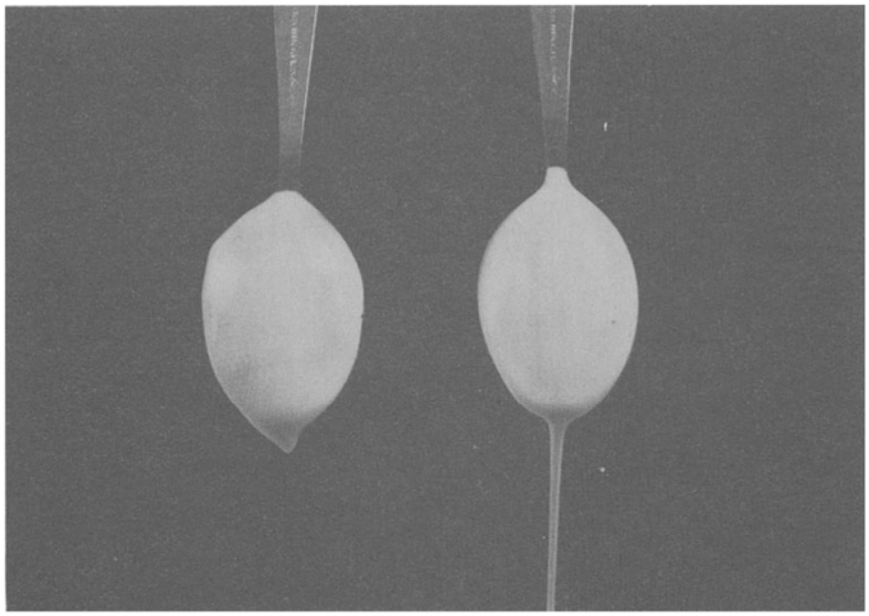


Figure 6.3 Mayonnaise used to make coleslaw is viscous and clings to a spoon (left). During the first six hours after mixing with the solid ingredients of the salad the viscosity of the mayonnaise decreases and it no longer clings (right).

(b) Solid phase/aqueous phase interaction – potato cells. Examination of Table 6.4 shows that although dilution of the mayonnaise caused by the movement of moisture from the vegetable tissue into the aqueous phase occurred in all of the salads studied it was not accompanied in all cases by the expected drop in viscosity. The observed increase in viscosity of the mayonnaise in the potato salad and the less than anticipated decrease in

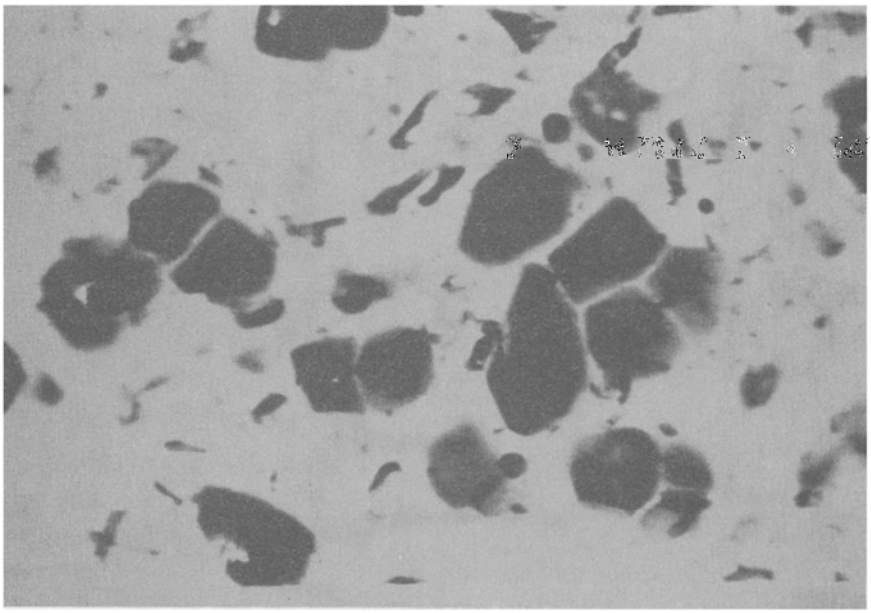


Figure 6.4 Potato cells in the mayonnaise of potato salad, which have sloughed off the cooked diced potato during the mixing of the salad. The cells contain gelatinised starch (stained here with iodine solution). (Micrograph prepared by Mary Parker, IFR Norwich.)

viscosity of the mayonnaise in the vegetable salad were probably due to the release of large numbers of free cells of potato tissue into the aqueous phase of the mayonnaise. These were cooked cells containing gelatinised starch (Figure 6.4), that had been sloughed from the outer surface of the pieces of parboiled diced potato in the salad during the mixing process. This interaction is an easily observed physical effect in that the potato cells confer a granular appearance on the mayonnaise. It is a mechanical effect that occurs immediately the potato tissue is mixed with the dressing. No further granularity occurs during shelf life and this interaction serves to decrease or reverse the somewhat deleterious effects of dilution with moisture on the viscosity of the dressing.

(c) Solid phase/aqueous phase interaction – organic acids. The concentration of undissociated organic acids in the aqueous phase of mayonnaise is fundamental to the microbiological stability of most dressed delicatessen salads, and it is usually the concentration of acetic acid that is the most important. As noted above, the effect of partition between the aqueous and lipid phases of dressings on the concentration of acetic acid is slight, and the pH and the concentration of undissociated acetic acid in the aqueous phase of dressings used in delicatessen salads are often quite suffi-

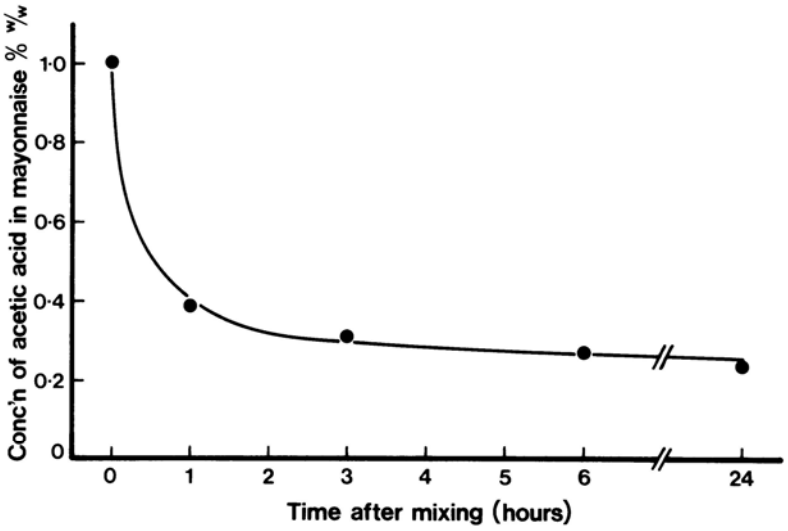


Figure 6.5 Migration of acetic acid from the mayonnaise of coleslaw into the vegetable tissue of the salad. The migration is completed within six hours of mixing the mayonnaise with the solid ingredients of the salad, and the concentration in the mayonnaise remains constant thereafter.

cient to render the dressings sterile. Nevertheless, it is this same aqueous phase in delicatessen salads that provides a hospitable environment for the growth of the microorganisms that can lead to the microbiological spoilage of the products. An appreciation of the interaction that occurs between the solid phase of these products and the undissociated organic acids in the aqueous phase is, therefore, essential if this change in the environment that eventually allows microbiological spoilage to occur is to be understood.

When the solid ingredients of the salad are mixed with the mayonnaise the undissociated acetic acid migrates into the vegetable tissue, from which it can be recovered quantitatively (Brocklehurst *et al.*, 1983; Brocklehurst and Lund, 1984). The migration occurs rapidly and is completed within six hours (Figure 6.5).

The decrease in the concentration of acetic acid in the aqueous phase of the product causes a concomitant increase in pH (Kirsop and Brocklehurst, 1982; Brocklehurst *et al.*, 1983; Brocklehurst and Lund, 1984; Boyar *et al.*, 1985), and this, combined with the dilution of the aqueous phase by the movement of moisture noted earlier, results in a new concentration of undissociated acetic acid far lower than that originally present (Table 6.5). This new level of acetic acid in the product is no

Table 6.5 Calculated concentrations of undissociated acetic acid (%w/w) and pH in the aqueous phase of mayonnaise[a] before making salads, and of mayonnaise separated from salads six hours after mixing

	Before making salad		Six hours after mixing	
Salad	pH	Concentration of undissociated acetic acid	pH	Concentration of undissociated acetic acid
Coleslaw	3.4	4.6	4.1–4.3	0.6
Florida salad	2.7	3.5	3.4–3.5	0.8
Potato salad	3.4	2.1	4.3–4.4	0.2
Vegetable salad	2.7	3.5	3.9–4.1	0.8
Spanish salad	2.7	3.5	3.6–3.8	1.0

[a]the proportion of the mayonnaise occupied by the aqueous phase was calculated by exclusion of the oils and solids.

longer microbicidal, but can permit the growth of microorganisms in the product limiting shelf life by causing spoilage.

(d) Solid phase/lipid phase interaction – oil. A fairly minor effect in those delicatessen salads that contain chopped or shredded leaf tissue (such as cabbage leaf tissue) is the movement of dispersed oil from the dressing into the air spaces of the leaf tissue (Boyar *et al.*, 1985). It is probably a consequence of the affinity between the oil fraction of the dressing and the waxy hydrophobic cuticle lining the air spaces, and is again complete within six hours after mixing the vegetable tissue with the dressing. Loss of oil from the mayonnaise in coleslaw by this mechanism was calculated to be only 5.2% of the total oil in the mayonnaise (Davies and Brocklehurst, 1986), but the effect of this redistribution on the cabbage tissue was marked. The tissue became translucent (Brocklehurst, 1984), and this was perceived in sensory analysis as a deteriorative change (Tunaley and Brocklehurst, 1982; Tunaley *et al.*, 1985).

6.3.2 Prepared fruit and vegetables

If these products contained a dressing they would have the characteristics of delicatessen salads. If the products were composed solely of entire fruits or vegetables their characteristics would be those of stored commodities. The fact that the products are composed of chopped or shredded components gives them characteristics that fall between these two categories. The act of chopping or shredding the tissues results in a very large cut surface area of damaged cells. This leads to considerable instability in the products which may then have a shelf life of only a few days, and it is interactions occurring within the products that again limit

shelf life. The extent of damage by machines or operatives can influence the rate at which deteriorative changes occur, both by the acceleration of physiological deterioration as a result of cellular rupture as well as contributing to exuded liquid. For example, shredded lettuce cut with a sharp knife using a slicing action had a shelf life about twice that of lettuce cut using a chopping action, and the use of a blunt knife decreased shelf life even further (Bolin *et al.*, 1977). These authors also showed that small shreds (1 mm thick) had a shorter shelf life than larger shreds (3 mm thick), which was related to the exposed cut surface area, and they and others (Bolin and Huxsoll, 1991) reduced damage and hence extended shelf life by tearing, rather than cutting, the lettuce leaf tissue.

6.3.2.1 Solid phase/aqueous phase interaction – moisture. Vegetable or fruit components used in the manufacture of these products are usually immersed in water or chlorinated water as part of a cleaning regime, and excess of water removed from the tissues, usually in a centrifuge, prior to packing. It might appear curious, therefore, to talk of an aqueous phase influencing the shelf life of these products, but, nevertheless, this is so. An aqueous phase is present as the film of liquid that exudes from the damaged surface of the tissue, and that contains moisture and nutrients. It can be added to by any washing water, and the presence of free moisture or cellular fluids on the surface of shredded lettuce decreased its shelf life (Bolin *et al.*, 1977; Bolin and Huxsoll, 1991). The cellular fluid on the cut surface of the tissue contains many enzymes including phenolase, catalase and peroxidase (Bolin *et al.*, 1977) and these can cause discoloration of the cut surfaces due to the oxidation of phenolic compounds, which can limit shelf life (Goupy, 1989). The loss of moisture can also lead to wilting or even desiccation of the tissues, and it is this exudate that allows the microorganisms associated with these products to multiply faster, and to greater numbers, than on intact tissues. Comparison of the relatively small numbers of bacteria on a leaf blade surface (Figure 6.6) with the large numbers forming a microbial film or colony on the cut surface (Figure 6.7) clearly demonstrates the importance of the cut surface in its contribution to the growth of microorganisms.

6.3.2.2 Solid phase/gaseous phase interaction – respiration. Fruit or vegetable tissue that has been damaged by cutting has a respiration rate higher than that of undamaged tissue (Priepke *et al.*, 1976; Brocklehurst and van Bentem, 1990) (Figure 6.8), although the extent of damage affecting the respiration rate is less if tissue is torn than if it is cut or shredded (Bolin and Huxsoll, 1991). The rate of respiration also increases as the temperature is raised.

Measurements made on mixed salad products (Table 6.6) showed that respiration rates could be as high as 82 mg CO_2/kg/hour during storage at

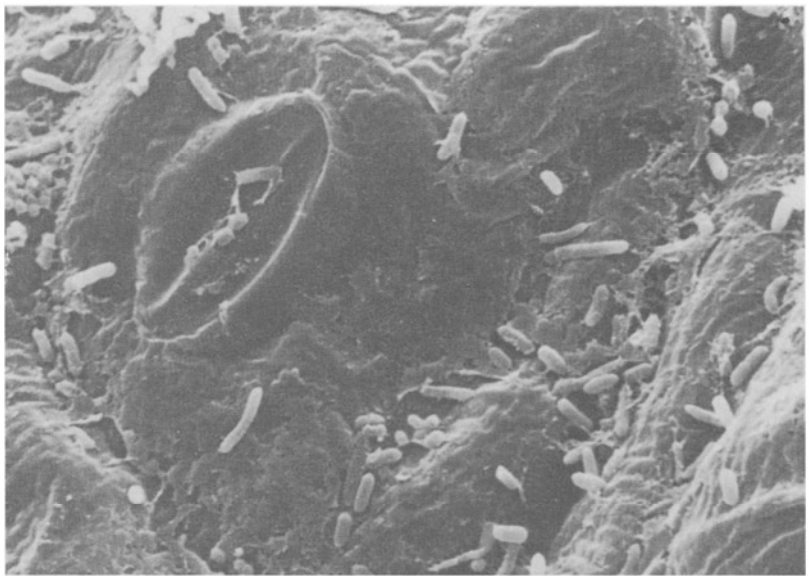


Figure 6.6 Scanning electron micrograph of bacteria on the blade of a piece of shredded lettuce leaf taken from a pack of prepared salad at the end of its shelf life. (Micrograph prepared by Mary Parker, IFR Norwich.)

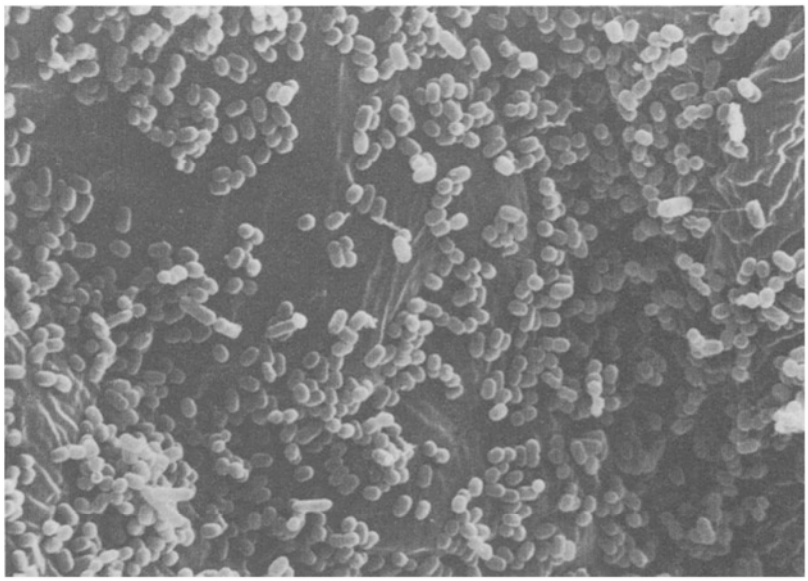


Figure 6.7 Scanning electron micrograph of bacteria on the cut surface of the piece of shredded lettuce leaf shown in Figure 6.6. (First published by Brocklehurst, T.F. and van Bentem, E. in *Food Science and Technology Today*, **4**(3), 156–8 (1990), and reproduced by courtesy of the publisher, the Institute of Food Science and Technology). (Micrograph prepared by Mary Parker, IFR Norwich.)

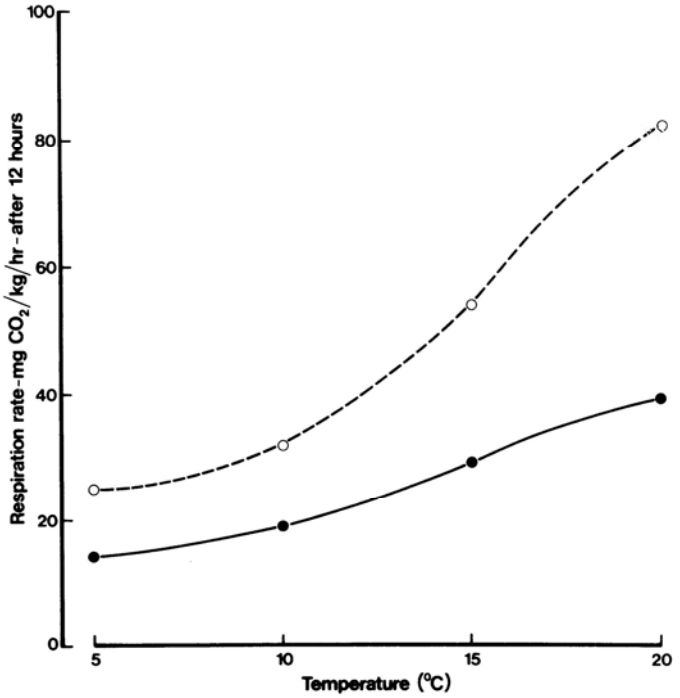


Figure 6.8 This graph shows that the respiration rate of shredded lettuce (○) is greater than that of whole lettuce (●) and that the respiration rates increase as the temperature increases. (First published by Brocklehurst, T.F. and van Bentem, E. in *Food Science and Technology Today*, **4**(3), 156–8 (1990), and reproduced by courtesy of the publisher, the Institute of Food Science and Technology.)

Table 6.6 Respiration rate[a] of chopped and shredded vegetable products during storage at 8°C

Pack contents	Respiration rate (mg CO_2/kg/hour)
Frise, radicchio, chicory, lambs lettuce	46
Chinese leaf, lettuce, frise, radicchio, red cabbage	38
Chinese leaf, white cabbage, cress, carrot, celery, red pepper, green pepper	82

[a]Unpublished reasurements made at the Institute of Food Research, Norwich

8°C, whereas similar commodities in their entire state had respiration rates of between 8 and 30 mg CO_2/kg/hour during storage at 10°C (Robinson *et al.*, 1975).

The result of such high rates of respiration can be to cause an over-modification of the pack atmosphere. This occurs when the packaging

material is insufficiently permeable to allow the rapid escape of CO_2 and ingress of O_2. Atmospheres that contained no detectable O_2 and concentrations of CO_2 as high as 16% (v/v) have been found within commercially-produced retail packs of mixed salad originally packaged in air (Brocklehurst *et al.*, 1987). Priepke *et al.* (1976) found concentrations of CO_2 as high as 20% (v/v) and O_2 as low as 1–2% (v/v) in packs of cut lettuce that again had been packed in air and stored at 4.4°C for 10 days. Concentrations of O_2 of less than 2% (v/v) induce anaerobic respiration of the vegetable and fruit tissues (Myers, 1989), and this can result in unacceptable organoleptic changes due to taints (McLachlan and Stark, 1985; Bolin and Huxsoll, 1991). Low concentrations of O_2 in these products may also present the hazard of the growth of anaerobic pathogenic bacteria such as *Clostridium botulinum* (Sugiyama and Yang, 1975; Tamminga *et al.*, 1978). Where packaging films do not allow any escape of the accumulated CO_2, an obvious swelling of the pack can result.

Some tissues create an overmodified atmosphere more readily than others. For example, Priepke *et al.* (1976) found that the respiration rate of cut lettuce decreased as the concentration of O_2 in the pack became almost totally depleted, and the carbon dioxide produced by the tissues was equivalent to the oxygen available to support aerobic respiration. In packs of cut carrot, however, the concentration of CO_2 exceeded that possible by utilisation of the available oxygen in the air within the pack. This indicated that anaerobic respiration had occurred, although the authors were unable to determine whether this was the result of respiration of the carrot tissue alone or microorganisms within the pack had contributed to the overall CO_2 level.

The extent of the modification of the pack atmosphere can influence the amount of exudation from the damaged cells, which in turn can affect shelf life by supporting the growth of microorganisms. The leakage of K^+ ions from plant tissues is a useful indicator of exudation. Carlin *et al.* (1990) showed that the concentration of K^+ ions leaking from grated carrots decreased during storage in air and under some modified atmospheres, but not in an atmosphere composed of 40% (v/v) CO_2 and 10% (v/v) O_2, where exudation increased during storage at 10°C.

6.4 Determination of shelf life

6.4.1 Delicatessen salads

From previous discussion, it should be clear that delicatessen salads are highly dynamic multiphase foods in which many interactions occur that quite rapidly change the physical and chemical state of the food from that pertinent at the time of manufacture. It is very important to describe the

chemical and physical state of these products as it exists after the redistributions have occurred, because it is these redistributions that dictate the eventual shelf life of the product. The interactions noted above serve to establish a chemical state in the entire product which, once established after the initial six hours after mixing, remains unchanged for the duration of the life of the product. These interactions, though, have destabilising effects on the products, which can lead to a wide range of deteriorative changes that undermine shelf life. Most published work concerns the shelf life of mayonnaise-based salads, and some examples of the factors that determine shelf life of these products follow.

6.4.1.1 Organoleptic changes in coleslaw during shelf life. Whereas microbiological spoilage occurred during the storage of coleslaw, it was preceded by sensory changes (Tunaley and Brocklehurst, 1982; Tunaley *et al.*, 1985). These are described here, and the microbiological studies, which parallel these sensory studies, are described in the next section.

The sensory changes occurred equally rapidly at 5°C and 10°C. The characteristics detected by a trained sensory panel as important in shelf life determination were 'creamy-oiliness', 'perceived acidity', and 'viscosity' which were assessed orally, and 'cabbage translucency' and 'mayonnaise consistency' which were assessed visually. For characteristics other than 'cabbage translucency' the panel assessed both the coleslaw and the mayonnaise which had been separated from the solid ingredients of the salad and found similar conclusions, suggesting that the sensory characteristics most important in the determination of shelf life of this product were those associated with the dressing.

The sensory analysis used a profile method (BSI, 1980), where characteristics were scored by placing a vertical mark along a 100 mm line at a position that the assessor felt best represented the perceived strength of each characteristic (Tunaley *et al.*, 1985).

The 'creamy-oily' characteristic included mouthfeel and a flavour component. Its decline during storage was considered a good indicator of ageing (Figure 6.9), but it was subject to seasonal variation probably related to the variety of cabbage used in the coleslaw (Tunaley and Brocklehurst, 1982; Tunaley *et al.*, 1985).

Perceived acidity, assessed orally, increased during storage (Figure 6.9), despite the absence of any change in the concentration of acetic acid in the mayonnaise after the initial redistribution, or any significant change in the pH. It has been suggested that changes in the physical properties of the mayonnaise that are related more to redistributions of oil and water may account for the apparent increase in perceived acidity during storage (Tunaley *et al.*, 1985).

Viscosity of the mayonnaise declined during storage as did the consistency which declined from 'coating' to 'very runny' (Figure 6.10).

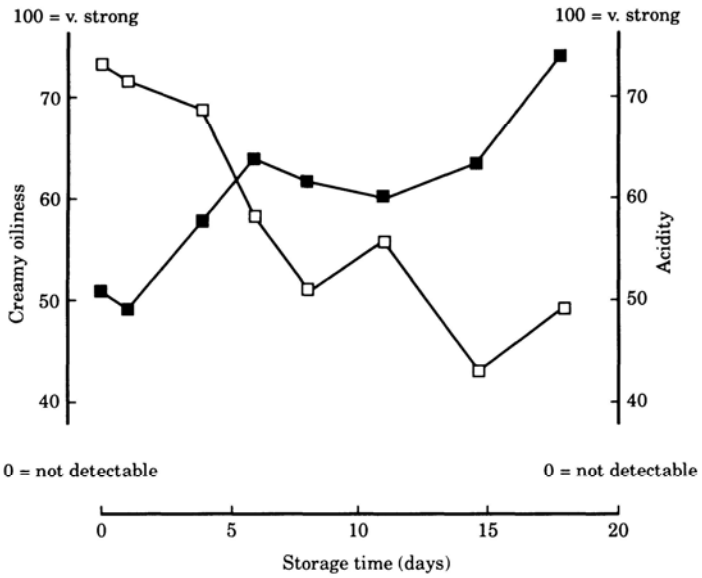


Figure 6.9 Changes in perceived creamy-oiliness (□) and perceived acidity (■) in mayonnaise separated from coleslaw stored at 5°C. (First published by Tunaley *et al.*, in *Food Science and Technology: Lebensmittel-Wissenschaft & Technologie*, **18**, 220–4 (1985), and reproduced by permission of the publisher, Academic Press, London.)

Overall this resulted in the progressive failure of the mayonnaise to coat the solid ingredients of the salad. The effect became more and more visible to the assessors, which was reflected in a perceived increase in translucency of the cabbage tissue with time (Figure 6.11) and this was described as 'aged', 'translucent' or 'grey'.

The flavour characteristic was affected by temperature and deterioration was greater at 10°C than at 5°C (Figure 6.12). This may have been evidence that the flavour change was the result of the activity of enzymes in the vegetable tissue (King *et al.*, 1976), some of which could also cause oxidative discoloration (Chen and Peng, 1980). After storage at 10°C for 18 days the assessors' descriptions included the terms 'mouldy', 'cheesy', 'sulphury', 'alcoholic', 'very acidic' and 'rancid' (Tunaley and Brocklehurst, 1982). Deterioration of the odour of coleslaw, faster at a higher (8°C) than lower (4°C) storage temperature, was also noted by Corry *et al.* (1980).

Whereas sensory analysis by a trained panel can give important insights into those quality attributes perceived as changing during shelf life, it is possible to equate some of them with instrumentally analysed parameters. Viscosity and consistency of mayonnaise were measured instrumentally by Tunaley *et al.* (1985) who found that the sensorily assessed attributes of

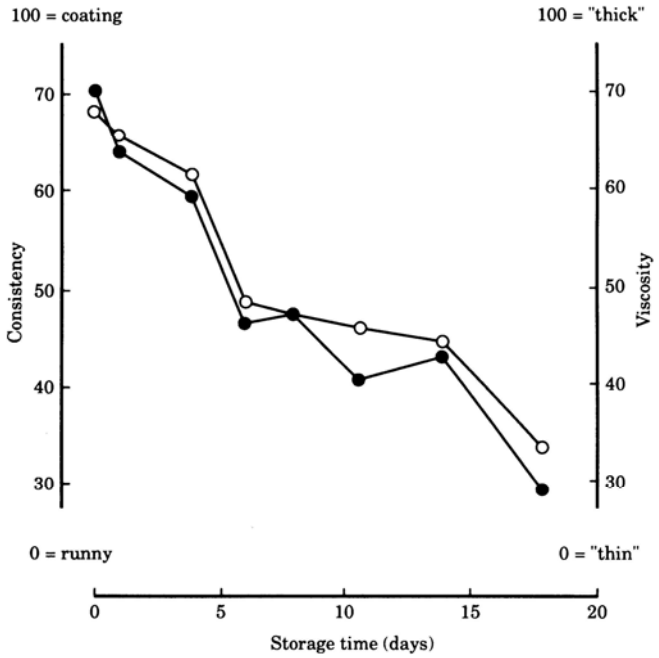


Figure 6.10 Changes in perceived viscosity (○) and perceived consistency (●) in mayonnaise separated from coleslaw stored at 5°C. (First published by Tunaley *et al.*, in *Food Science and Technology: Lebensmittel-Wissenschaft & Technologie*, **18**, 220–4 (1985), and reproduced by permission of the publisher, Academic Press, London.)

perceived consistency, perceived creamy-oiliness and perceived viscosity correlated well with the instrumental measurement of viscosity and that the perceived creamy-oiliness correlated well with instrumentally measured consistency.

6.4.1.2 Microbiological changes in mayonnaise-based salads during shelf life. Just as changes in the sensory attributes of these products have their origins in the interactions that occur during the first few hours after a salad is made, so the change in concentration of the undissociated acetic acid during this time is critical to the survival and growth of certain microorganisms in the product. Delicatessen salads are subject to spoilage due mainly to the growth of bacteria and yeasts. These may appear as colonies on the surface of the product (Figures 6.13 and 6.14) or they may cause spoilage due to the production of carbon dioxide within the dressing (Norberg and Åkerstrand, 1980; Wiberg *et al.*, 1983; Brocklehurst, 1984; Geeson *et al.*, 1987) (Figure 6.15). Although microbiological spoilage usually manifests itself after the sensory changes in the product

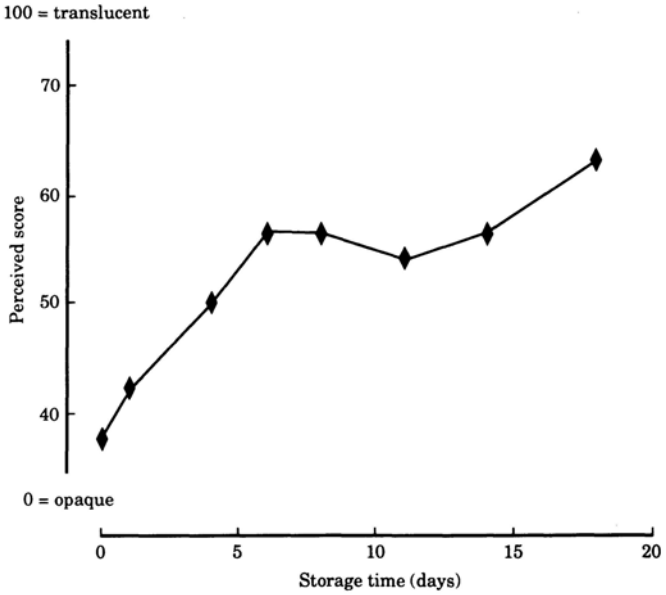


Figure 6.11 Changes in perceived translucency of cabbage separated from coleslaw stored at 5°C. (First published by Tunaley *et al.*, in *Food Science and Technology: Lebensmittel-Wissenschaft & Technologie*, **18**, 220–4 (1985), and reproduced by permission of the publisher, Academic Press, London.)

have become evident, it is, nevertheless, a form of spoilage very obvious to the consumer.

Delicatessen salads can contain very many different types of bacteria and yeasts at the time of manufacture (Hankin and Ullman, 1969; Christianson and King, 1971; Fowler and Clark, 1975; Harris *et al.*, 1975; Pace, 1975; Terry and Overcast, 1976; Rose, 1984; Greenwood *et al.*, 1975), these being derived from the solid ingredients of the products and from the processing plant (Collins, 1982). By virtue of its organic acid content and its pH, the dressing is usually fully preserved. Typically, only a few species of bacteria and yeasts multiply in these products. The yeasts are predominantly *Saccharomyces exiguus* and *Pichia membranaefaciens* and the bacteria are predominantly *Lactobacillus* spp. (Holtzapffel and Mossel, 1968; Baumgart and Hauschild, 1980; Baumgart *et al.*, 1983). In a study of 24 different mayonnaise-based delicatessen salads, Geeson *et al.* (1987) found that *Saccharomyces exiguus* was present at greater than 10^5 g^{-1} of salad at the end of shelf life in 17 of the salads and that *Pichia membranaefaciens* was present at greater than 10^5 g^{-1} of salad at the end of shelf life in four of them. *Saccharomyces exiguus* is a fermentative yeast and causes spoilage due to production of carbon dioxide in the mayon-

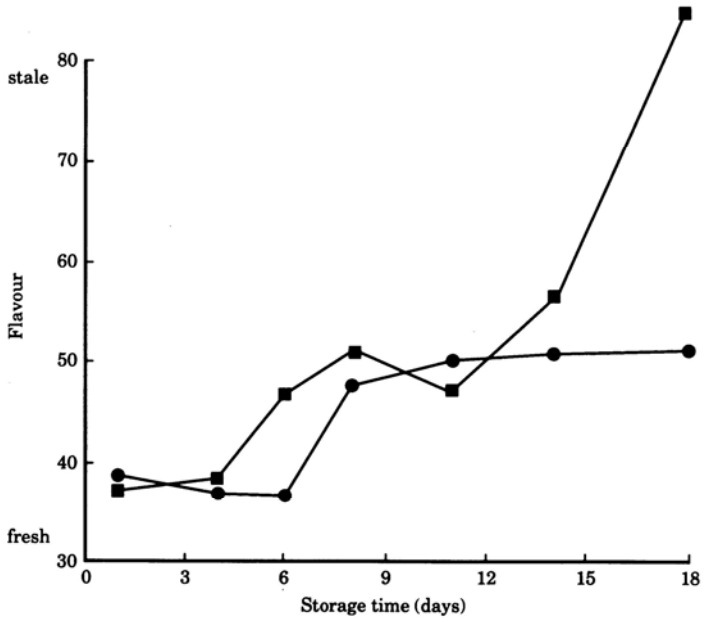


Figure 6.12 Changes in flavour of coleslaw stored at 5°C (●) and 10°C (■). (First published by Tunaley, A. and Brocklehurst, T.F. in *Chilled Foods*, Nov/Dec, 12–13 (1982), and reproduced by permission of the publisher, FMJ International Publications Ltd.)

naise (Figure 6.15). *Saccharomyces dairensis* has also occasionally been implicated in spoilage of mayonnaise-based salads (Dennis and Buhagiar, 1980; Brocklehurst *et al.*, 1983). Although this yeast is less tolerant to acetic acid than *Saccharomyces exiguus*, it is also fermentative, and was found to reach numbers likely to cause spoilage in a product that had been stored at 10°C for about 20 days (Brocklehurst *et al.*, 1983). *Pichia membranaefaciens* is an aerobic yeast and causes spoilage due to the formation of surface colonies (Figures 6.13 and 6.14).

The complexity and rate of growth of the associative microflora of mayonnaise-based salads were found to relate to the residual concentration of acetic acid in the dressing and its pH after the migration of acetic acid had occurred, and the storage temperature.

The following examples of the microbiology of delicatessen salads are from the work of Brocklehurst and Lund (1984):

1. In a potato salad where the residual concentration of undissociated acetic acid in the aqueous phase of the dressing was 0.2% (w/w) at pH 4.3–4.4 (Figure 6.16), the microorganisms able to grow in the product during storage at 10°C were mainly lactobacilli and the yeasts *Saccharomyces exiguus*, *Candida sake*, *Candida lambica* and *Yarrowia lipolytica*

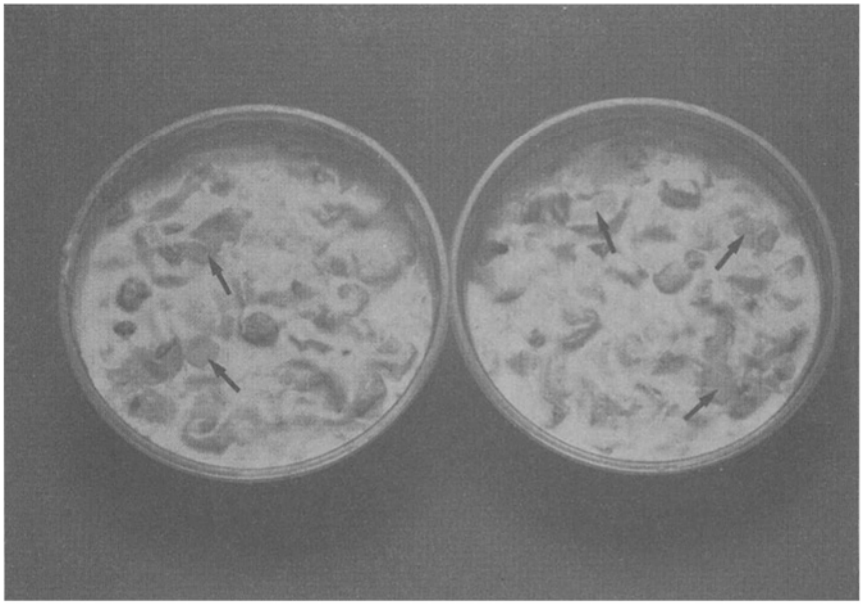


Figure 6.13 At first glance the colonies of the spoilage yeast *Pichia membranaefaciens* (arrowed) seen here growing on the surface of vegetable salad during storage at 10°C, could be confused with vegetable ingredients. (First published by Brocklehurst, T.F. in *Food Manufacture*, April, 65 and 67 (1984) and reproduced by permission of the publisher, Morgan-Grampian (Process Press) Ltd.)

and *Geotrichum candidum*. Spoilage occurred after storage for 10 days and was due to gas production probably by both *Saccharomyces exiguus* and the lactobacilli.

2. In a coleslaw, however, where the residual concentration of undissociated acetic acid in the aqueous phase of the dressing was 0.6% (w/w) at pH 4.1–4.3, lactobacilli and other bacteria declined in numbers. Only *Saccharomyces exiguus* was able to multiply during storage at 10°C (Figure 6.17), subsequently causing spoilage due to gas production after 21 days.
3. *Saccharomyces exiguus* also predominated in a Florida salad, where the concentration of undissociated acetic acid was 0.8% (w/w) and the pH was 3.4–3.5, where it caused spoilage after storage at 10°C for 13 days (Figure 6.18).
4. In a vegetable salad where the concentration of undissociated acetic acid was 0.8% (w/w) and the pH was 3.9–4.1, spoilage due to gas production caused by the growth of *Saccharomyces exiguus* occurred after storage at 10°C for 8 days, but colonies of *Pichia membranaefaciens* appeared on the surface of the salad after 14 days (Figure 6.19).

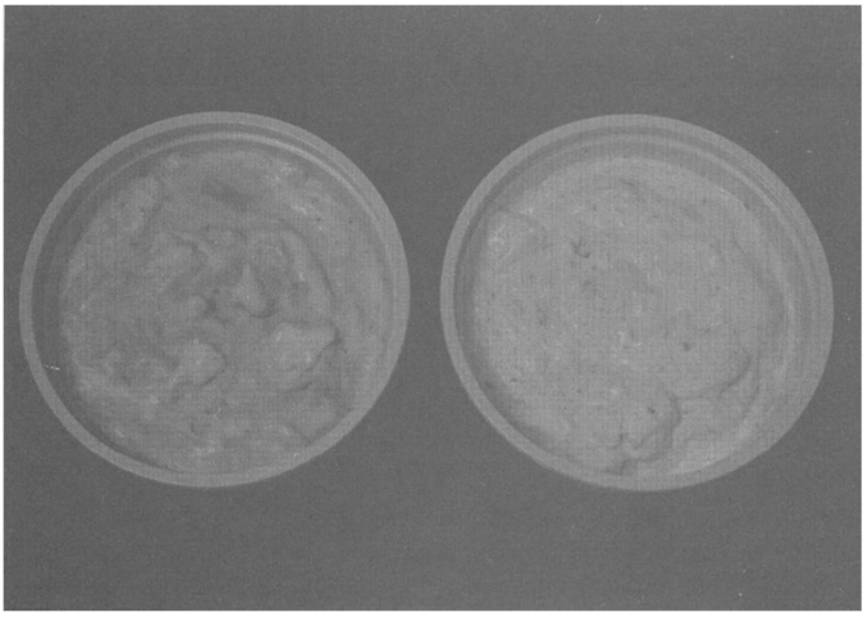


Figure 6.14 Potato salad (right) and the product after very obvious spoilage due to the growth of colonies of the yeast *Pichia membranaefaciens* on the surface.

5. In a Spanish salad, on the other hand, the residual concentration of undissociated acetic acid in the aqueous phase of the dressing remained high at 1% (w/w) and the pH was at 3.6–3.8. During storage at 10°C, this product was found to support only slight growth of spoilage organisms (Figure 6.20).

It is evident, therefore, that the residual concentration of acetic acid in the aqueous phase of the dressing and the pH at equilibrium determined the survival of the naturally occurring microflora and their rate of growth, and hence influenced the microbiological spoilage of these products.

Temperature of storage is, of course, also important. During storage of these salads at 5°C neither the Florida salad, coleslaw nor Spanish salad supported the growth of microorganisms. The vegetable salad supported the growth of *Pichia membranaefaciens* and small numbers of lactobacilli, whereas the potato salad supported growth of *Candida zeylanoides*, *Candida lambica*, *Yarrowia lipolytica*, *Geotrichum candidum*, and lactobacilli and was the only salad to show microbiological spoilage at this temperature, but only after storage for 28 days (Brocklehurst and Lund, 1984).

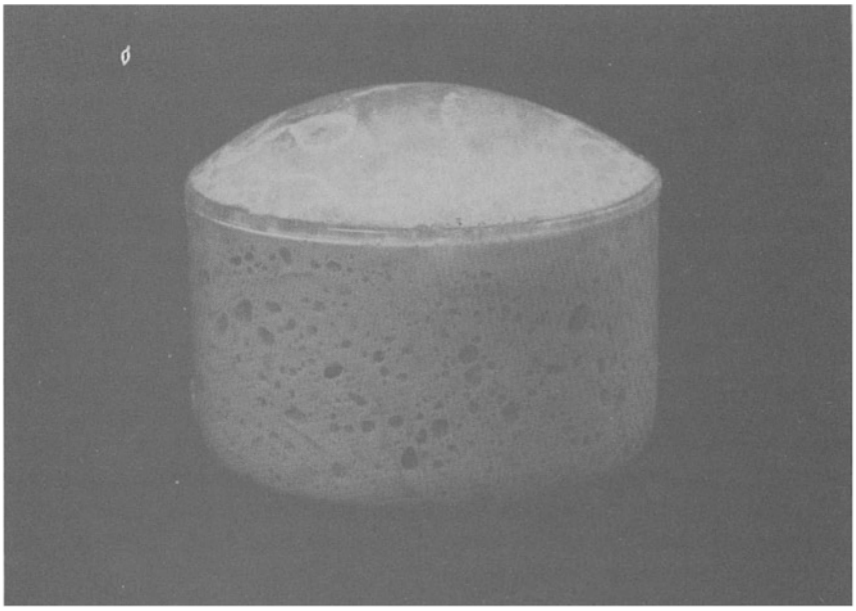


Figure 6.15 Spoilage of coleslaw due to gas production caused by growth of the spoilage yeast *Saccharomyces exiguus*. (First published by Geeson *et al.*, in *Food*, February, 49–53 (1987) and reproduced by permission of the publisher, Turret Group.)

6.4.1.3 Changes in minor ingredients. The sensory and microbiological changes described above are the most important determinants of the shelf life of mayonnaise-based delicatessen salads. They are related to the various interactions that occur in the products and such changes could therefore be used to predict shelf life. Changes in the quality of many of the minor ingredients of delicatessen salads have been monitored by Geeson *et al.* (1987) (Table 6.7) and, although these changes may be encountered in any delicatessen product, they are unlikely to be regarded as significant enough to limit shelf life.

6.4.2 Prepared fruit and vegetables

The interactions occurring within prepared fruit and vegetable products are fewer than those identified in delicatessen salads, but they nevertheless combine to limit shelf life.

6.4.2.1 Changes in microflora. Visual assessment of product quality judged that products with a high initial number of bacteria (5.1×10^6 g^{-1} of salad) declined in quality faster than products with a lower number

Table 6.7 Changes in quality of some ingredients of mayonnaise-based salads during storage at 5° or 10°C[a]

Ingredient	Quality change
Apple	Brown discoloration of cut surface
Cabbage	Discoloration and translucency
Carrot (cooked)	Fragmentation and discoloration
Celeriac	Discoloration
Celery	Discoloration
Cheese	Development of odours described as 'butyric', 'plastic', 'fermented'
Mandarin orange	Fragmentation
Peas	Yellow discoloration
Red and green peppers	Discoloration
Potato (cooked)	Appearance described as 'grey' or 'glassy', fragmentation, development of strong 'earthy' odours
Prawns	Development of strong 'off' fishy odours
Walnuts	Leaching of colour into mayonnaise, development of strong 'mealy' odours

[a]First published by Geeson *et al.* (1987) and used by kind permission of the publisher, Turret Group plc.

(5.8×10^3 g^{-1} of salad) (Bolin *et al.*, 1977). Nguyen-The and Prunier (1989) found that the numbers of pectolytic pseudomonads in fruit and vegetable products were directly related to their deterioration.

At the time of packing the number of microorganisms associated with these products is often large. Bacteria, yeasts and moulds are included (Manvell and Ackland, 1986; Nguyen-The and Prunier, 1989; Brocklehurst and van Bentem, 1990; Garg *et al.*, 1990) and many of these multiply during storage. For example, numbers of *Pseudomonas* spp. and lactic acid bacteria in excess of 10^8 g^{-1} have been isolated from retail packs of salad after storage at 7°C or 10°C, at the end of their shelf life (Brocklehurst *et al.*, 1987; Nguyen-The and Prunier, 1989).

Some of the bacteria associated with the natural flora of prepared vegetables (such as *Bacillus* spp., *Cytophaga* spp., *Erwinia* spp., *Pseudomonas* spp.) (Nguyen-The and Prunier, 1989; Brocklehurst *et al.*, 1987) can cause deterioration due to the production of pectic enzymes. These degrade the pectic substances inside the middle lamella between individual cells which cement together the cell walls of plant tissues. This degradation can lead to loss of turgor of the cells and can proceed to give soft-rotted areas of the tissue resulting in a translucent or watersoaked appearance.

Published studies of the microbiological changes that occur in these products during storage are confined largely to prepared vegetable products, and the comments that follow refer to these.

The predominant microorganisms present in packs of prepared vegetable salad products at packing include a wide range of Gram-positive and Gram-negative bacteria, such as members of the Enterobacteriaceae

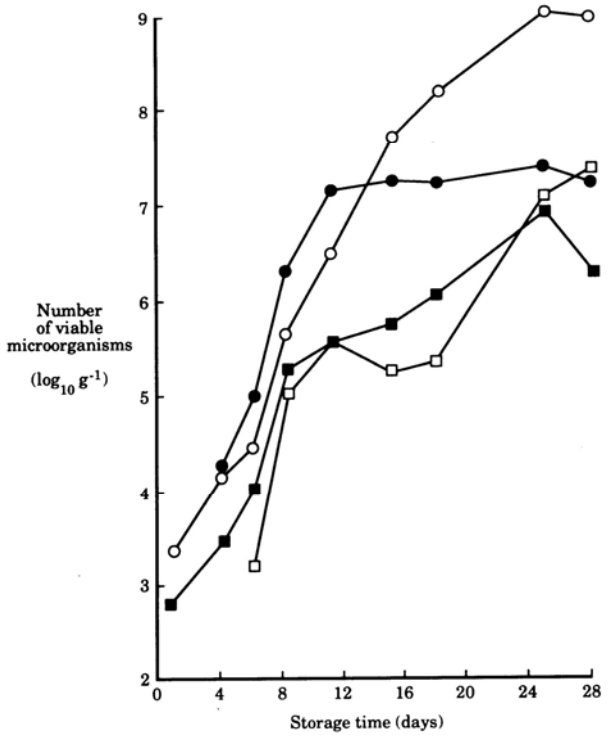


Figure 6.16 Changes in the microflora of potato salad during storage at 10°C. The salad had a pH of 4.3–4.4 and a residual concentration of undissociated acetic acid in the aqueous phase of the mayonnaise of 0.2% (w/w). ○, Lactobacilli; ●, *Saccharomyces exiguus*; □, *Geotrichum candidum*; ■, *Candida* species. (First published by Brocklehurst, T.F. and Lund, B.M. in *Food Microbiology*, **1**, 5–12 (1984) and reproduced by permission of the publisher, Academic Press, London.)

and Streptococcaceae, *Pseudomonas* spp., *Flavobacterium* spp., lactic acid bacteria and yeasts (Shapiro and Holder, 1960; Manvell and Ackland, 1986; Brocklehurst *et al.*, 1987). These are derived mainly from the naturally associated microflora of the plant tissues, but some sites within processing factories (particularly shredders and slicers) can be accumulation points for microorganisms, and could give rise to subsequent contamination of processed materials (Garg *et al.*, 1990).

Storage of these products at 8°C resulted in the multiplication of bile tolerant bacteria, *Pseudomonas* spp., lactic acid bacteria, yeasts and moulds (Manvell and Ackland, 1986; Brocklehurst *et al.*, 1987). This microbial growth was accompanied by a decrease in the concentration of oxygen and an increase in the concentration of carbon dioxide in the pack (Brocklehurst and van Bentem, 1990) (Figures 6.21 and 6.22), although this change in the gaseous composition could have been the result of the

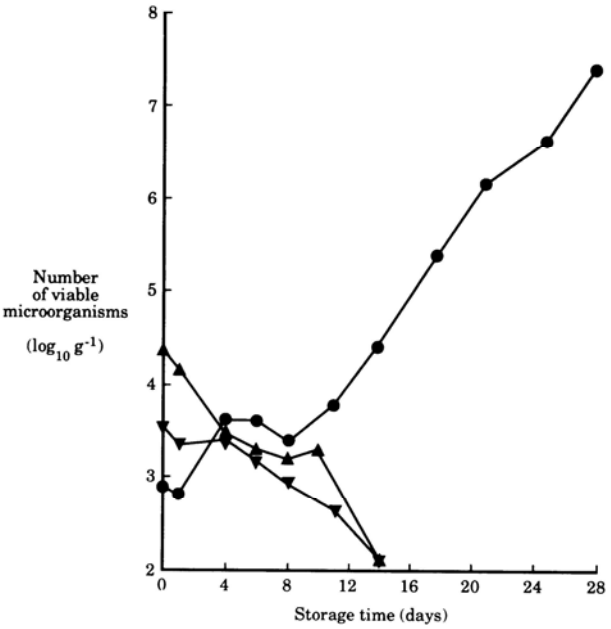


Figure 6.17 Changes in the microflora of coleslaw during storage at 10°C. The salad had a pH of 4.1–4.3 and a residual concentration of undissociated acetic acid in the aqueous phase of the mayonnaise of 0.6% (w/w). ●, *Saccharomyces exiguus*; ▲, Lactobacilli; ▼, other bacteria. (First published by Brocklehurst, T.F. and Lund, B.M. in *Food Microbiology*, **1**, 5–12 (1984) and reproduced by permission of the publisher, Academic Press, London.)

respiration of the plant tissue and the microorganisms. Such increases in the concentration of CO_2 within the pack favoured the multiplication of yeasts and lactic acid bacteria in packs of grated carrot (Carlin *et al.*, 1990). Babic *et al.* (1992) considered, though, that neither the number of yeasts nor the composition of the yeast flora were directly related to product shelf life. Manvell and Ackland (1986) suggested that the number of Gram-negative bacteria in these products was an important determinant of shelf life and used the *Limulus* lysate test as an indicator of shelf life. They also found that when products were stored at 30°C, lactic acid bacteria predominated, and these authors suggested, therefore, that an assay of the concentration of lactic acid produced as a by-product of the growth of lactic acid bacteria could be used as an indicator of temperature abuse. Other bacteria of significance isolated from retail packs have included *Escherichia coli* type 1, *Listeria monocytogenes*, *Yersinia intermedia*, and *Yersinia enterocolitica* (Brocklehurst *et al.*, 1987; Sizmur and Walker, 1988), although Brackett (1987) also lists a range of potential hazards derived from viruses and parasites in these kinds of products.

Products that contain prepared fruits or pieces of fruit are becoming

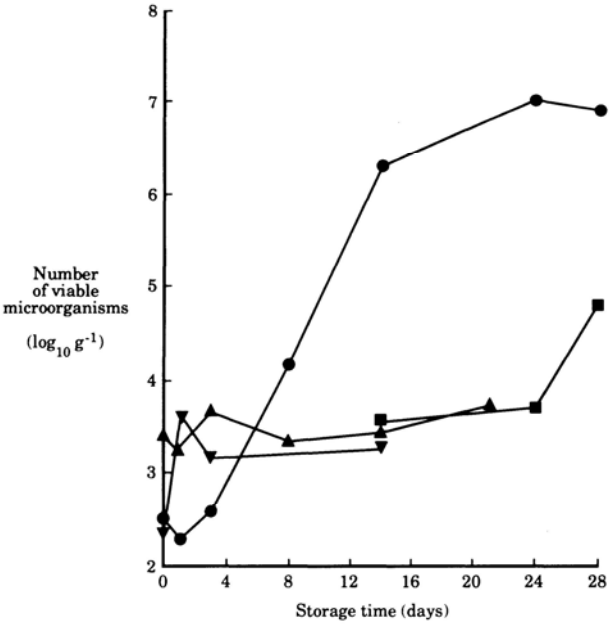


Figure 6.18 Changes in the microflora of Florida salad during storage at 10°C. The salad had a pH of 3.4–3.5 and a residual concentration of undissociated acetic acid in the aqueous phase of the mayonnaise of 0.8% (w/w). ●, *Saccharomyces exiguus*; ■, *Pichia membranaefaciens*; ▲, Lactobacilli; ▼, other bacteria. (First published by Brocklehurst, T.F. and Lund, B.M. in *Food Microbiology*, **1**, 5–12 (1984) and reproduced by permission of the publisher, Academic Press, London.)

more popular. The shelf life of these products will be constrained by the same types of interactions that influence the shelf life of vegetable products, except that the microflora will differ. The pH of the exudate from vegetable tissues is usually between pH 5.8 and 7.3, and hence it readily supports growth of bacteria. Fruit exudate, however, is more acidic and has a pH between 2.4 and 5.2 (von Schelhorn, 1951), and it tends to select for the growth of yeasts, moulds and lactic acid bacteria as the predominant microflora (Goepfert, 1980).

6.4.2.2 Organoleptic changes. The products may contain very large numbers of bacteria and yeasts that do not have an obvious influence on the quality of the product. In these cases the shelf life has been shown often to be determined by the rate of deterioration in colour, texture or flavour of the vegetable tissue components (King and Bolin, 1989), and oxidative discoloration, and pectinolytic and flavour changes of fruit slices (Heaton *et al.*, 1969; Ponting *et al.*, 1972). Many of these changes result from physiological processes that are inevitable in living tissues, but that are accelerated by tissue damage (Rolle and Chism, 1987). Loss of texture

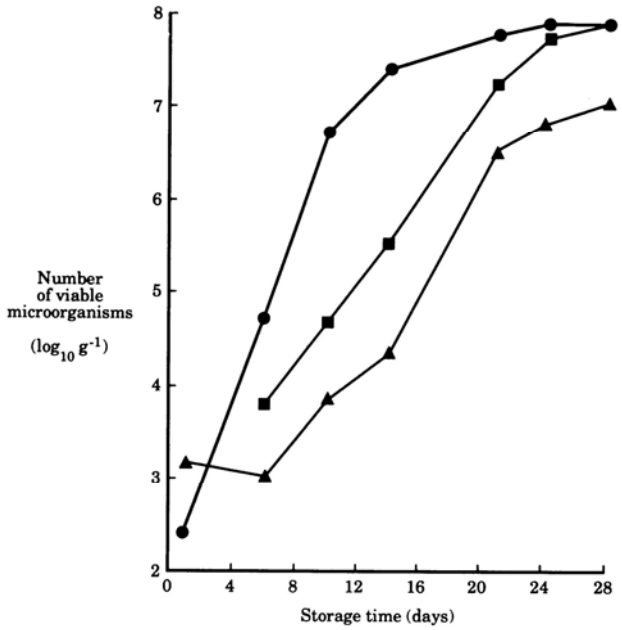


Figure 6.19 Changes in the microflora of vegetable salad during storage at 10°C. The salad had a pH of 3.9–4.1 and a residual concentration of undissociated acetic acid in the aqueous phase of the mayonnaise of 0.8% (w/w). ●, *Saccharomyces exiguus*; ■, *Pichia membranaefaciens*; ▲, Lactobacilli. (First published by Brocklehurst, T.F. and Lund, B.M. in *Food Microbiology*, **1**, 5–12 (1984) and reproduced by permission of the publisher, Academic Press, London.)

is related to a weakening of the polymeric structures of the plant cell wall and may be accompanied by a loss of turgor (King and Bolin, 1989), which is a result of exudation (Carlin *et al.*, 1990). Bolin *et al.* (1977) and Bolin and Huxsoll (1991) found that shredded lettuce darkened during storage, and that this change was accompanied by a loss in visual green pigmentation, which was greater at 10°C than at 5°C and greater at 5°C than at 2°C. This decrease in colour is usually accompanied by an increase in the discoloration of cut surfaces due to the action of the enzyme phenolase (King and Bolin, 1989). Flavour and appearance were judged on a hedonic scale by Priepke *et al.* (1976), who found that during storage of cut vegetables (lettuce, carrot, endive, celery, and radish), these attributes deteriorated faster than in intact tissue. Williams (1990) also found discoloration, odor development and drying of tissues to be determinants of shelf life in prepared mixed salads, and showed that the temperature dependence of these changes followed a square root relationship.

Constituents that might contribute to taste or flavour were studied by

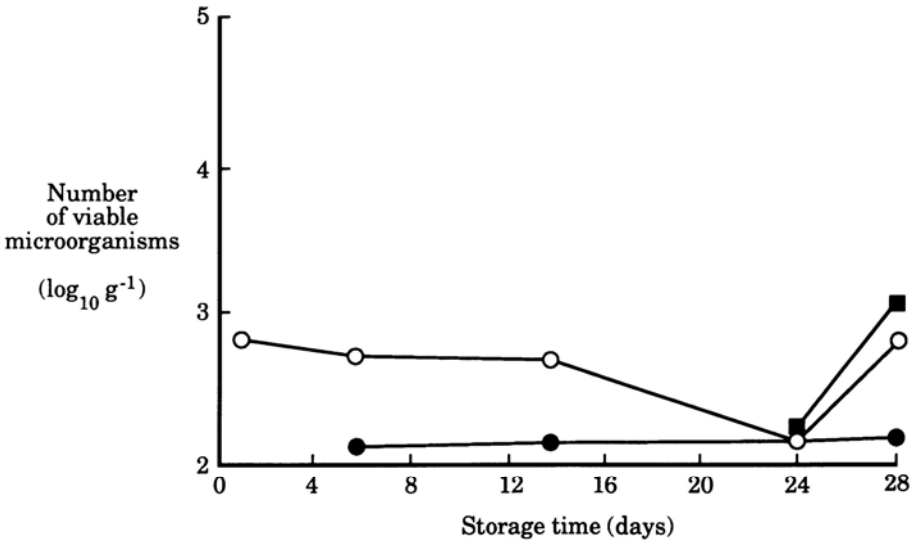


Figure 6.20 Changes in the microflora of Spanish salad during storage at 10°C. The salad had a pH of 3.6–3.8 and a residual concentration of undissociated acetic acid in the aqueous phase of the mayonnaise of 1.0% (w/w). ○, Lactobacilli; ●, *Saccharomyces exiguus*; ■, *Pichia membranaefaciens*. (First published by Brocklehurst, T.F. and Lund, B.M. in *Food Microbiology*, **1**, 5–12 (1984) and reproduced by permission of the publisher, Academic Press, London.)

Bolin and Huxsoll (1991). They found that the concentration of sugars and the titratable acidity of cut lettuce did not change during storage at 2°C, but the content of soluble solids, which would have included storage polysaccharide, declined and this was possibly due to the utilisation of carbohydrate by respiration.

Carlin *et al.* (1990) found that the concentrations of sucrose (which has considerable influence on carrot taste, Rumpf and Hansen, 1973), glucose, fructose and malic acid in grated carrots decreased dramatically during storage in air at 10°C, although the rates of disappearance of these constituents from this tissue could be slowed down by modification of the gaseous atmosphere.

Flavour taints caused by anaerobiosis of the plant tissue are related to the oxygen concentration within the pack and the threshold concentration at which the tissue becomes anaerobic (McLachlan and Stark, 1985). The end products of anaerobic metabolism are usually lactic and acetic acids and ethanol (Carlin *et al.*, 1989) although these authors suggested that the concentrations of these in the pack could be derived from the contaminating lactic acid bacteria as well as from the vegetable tissues.

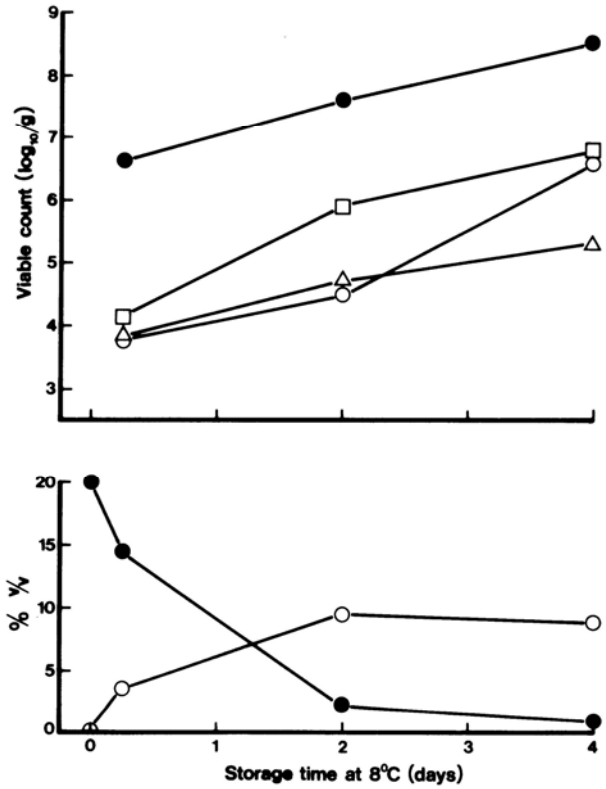


Figure 6.21 Changes in the microflora, and in the composition of gaseous atmosphere, of a pack of prepared mixed salad packaged in a tray and overwrapped with PVC cling film (15 μ in thickness) during storage at 8°C. The pack contained shredded Chinese leaf, shredded white cabbage, shredded carrot, chopped celery, chopped red pepper, chopped green pepper, cress and sweetcorn. Upper graph: ●, Pseudomonads; ○, lactic acid bacteria; △, yeasts and moulds; □, bile tolerant lactose fermenting organisms. Lower graph: ●, O_2; ○, CO_2. (First published by Brocklehurst, T.F. and van Bentem, E. in *Food Science and Technology Today*, **4**(3), 156–8 (1990), and reproduced by courtesy of the publisher, the Institute of Food Science and Technology (UK).)

6.5 Current developments and the future

6.5.1 Delicatessen salads

A logical development for the mayonnaise-based salads industry is the production of entire mini-meals based on the salads concept. Such products are in keeping with the image of a healthy diet, and they offer the manufacturer an opportunity for added value. What has limited this progression, however, has been the inherent difficulty in making a product that is both bland and safe. The product must be bland in order to allow

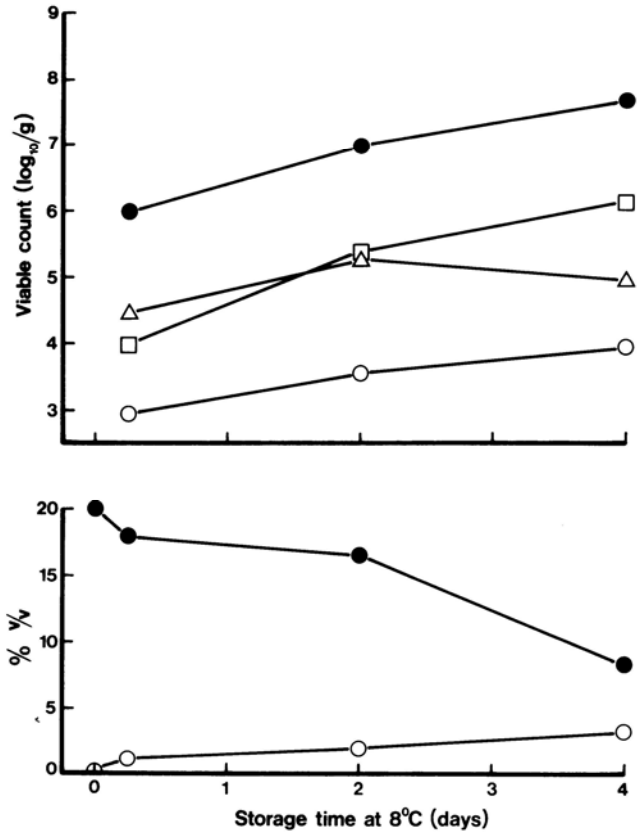


Figure 6.22 Changes in the microflora, and in the composition of gaseous atmosphere, of a pack of prepared mixed salad packaged in a tray and overwrapped with PVC cling film (19 μ in thickness) during storage at 8°C. The pack contained shredded frise, shredded radicchio, shredded chicory and lambs lettuce. Upper graph: ●, Pseudomonads; ○, lactic acid bacteria; △, yeasts and moulds; □, bile tolerant lactose fermenting organisms. Lower graph: ●, O_2; ○, CO_2.

consumption of the quantity needed to constitute a mini-meal, and yet a mild product would not have sufficient concentration of antimicrobial acids to ensure either microbiological safety or a sufficiently long shelf life.

This kind of development necessitates a thorough understanding and analysis of the chemical and physical interactions occurring within the products. Predictions that relate the concentration of undissociated acetic acid remaining in the aqueous phase of the mayonnaise after interactions have occurred within the product to that concentration required to inhibit the growth of microorganisms of interest could be described as follows:

target concentration of organic acid required	=	function of the total concentration of organic acid	×	effect of migration	×	effect of pK_a and pH of food on dissociation	×	effect of partition

Information about the inhibitory concentrations of organic acids can be derived from the literature or from databases that are actively under construction in the UK and elsewhere, such as the newly introduced Food Micromodel by the UK Ministry of Agriculture, Fisheries and Food (MAFF, 1992).

The use of buffering systems within dressed salads has been adopted occasionally (Debevere, 1987). Buffer systems operate by creating a high concentration of weak acid and its salt (for example citric acid and trisodium citrate or acetic acid and sodium acetate) in the aqueous phase of the mayonnaise. The buffering system in the case of an acetate/acetic acid buffer operates as follows:

$$\underset{\text{undissociated acetic acid}}{CH_3COOH} \underset{\text{acidity increases}}{\overset{\text{acidity decreases}}{\rightleftharpoons}} \underset{\text{dissociated acetate ion}}{CH_3COO^-} + \underset{\text{proton}}{H^+} \qquad (6.5)$$

When a change occurs in the food that increases its acidity (which is really an increase in the concentration of protons or H^+ ions) the protons combine with the acetate ions to produce undissociated acid and the influence of these protons is therefore negated. Likewise when the food becomes less acidic, equation (6.5) is driven to the right and the acid dissociates to release protons and the pH is kept constant. In theory these systems offer a means of introducing into foods a large reservoir of undissociated acid that remains microbicidal at a range of pH values (Debevere, 1987), although the actual concentration range is restricted because of organoleptic implications.

An attractive feature of many mayonnaise-based salads is the incorporation of high protein ingredients such as cheese, chicken meat, corned beef, crab meat, egg, ham, herring meat, mycoprotein, prawns or sausage. These ingredients give significant added value to the product, but their inclusion usually results in a food that has a higher pH than if the protein ingredient were absent (Rose, 1984). For example, the pH of mayonnaise-based salads without protein ingredients is usually in the range of pH 3.2–4.5. The addition of cheese elevated this to pH 4.0–4.5, fish elevated this to pH 3.6–4.4, meat to pH 4.0–5.1 and seafood to pH 3.7–4.5. This has implications for the safety and microbiological stability of the products. There are suggestions that the protein components could confer some protection on the contaminating bacteria from the hostile environment of the dressing. For example, McKinley *et al.* (1974) showed that

the food-borne pathogenic bacterium *Staphylococcus aureus* was protected from the acidic environment within the mayonnaise when it was inoculated into a mayonnaise-based salad as a contaminant of chicken meat.

Modified atmosphere packaging (MAP) of mayonnaise based salads has been introduced, although it is not used widely and published studies suggest that it is not always beneficial. For example, studies by Buick and Damoglou (1989) showed that a gaseous atmosphere of 20% (v/v) CO_2 and 80% (v/v) N_2 delayed the microbiological spoilage of a mayonnaise-based vegetable salad stored at 4°C, 10°C or 15°C by inhibiting growth of the spoilage yeasts. However, studies by Ahvenainen *et al.* (1990) that used a storage temperature of 5°C did not result in growth of spoilage microorganisms, but the use of gaseous atmospheres that contained concentrations of CO_2 greater than or equal to 20% (v/v) caused organoleptic deterioration of a mayonnaise-based potato salad during the shelf life. The CO_2 caused flavour changes described as 'oldish', 'sour', 'rancid' or 'oxidised off-taste' from the beginning of storage. These changes became more noticeable as the concentration of CO_2 was increased, and the flavour continued to deteriorate throughout storage.

Pasteurisation is a processing option that does not fit easily with the 'fresh' image of these products. Nevertheless, pasteurised salads have been marketed, although spoilage of these caused by acid-tolerant *Clostridium* spp. has been documented (Baumgart *et al.*, 1984). In addition, the flavour of the mayonnaise can deteriorate upon heating (Cerny and Hennlich, 1983), although developments have taken place that claim to overcome these changes by the use of thermostable mayonnaise ingredients (Galvin, 1991).

Market trends have resulted in the appearance of new dressings that reinforce the 'healthy eating' image of this product range. Dressings that have low oil content or that are 'virtually fat free' may appeal to the consumer, although work on the influence of these dressings on the organoleptic and microbiological quality of the salad products has not been published. Dressings based on yogurt or sour cream will probably also be reintroduced, and an interest in fermented dressings is emerging in the literature (Bonestroo *et al.*, 1993).

6.5.2 Prepared fruit and vegetables

Modification of the gaseous atmosphere of these products is applied quite widely in Europe and in the USA, although currently less so in the UK. The rationale behind MAP is to decrease the concentration of oxygen in the packs and poise it at a concentration that will diminish the extent of oxidative discoloration that leads to spoilage (McLachlan and Stark, 1985). MAP can also be used to retard ripening and senescence processes (Isenberg, 1979; Myers, 1989).

The concentration of gases within MAP products should be such that the production of CO_2 and consumption of O_2 by the respiring tissues is balanced by the gas transmission through the packaging material. The appropriate gas composition may be achieved by the respiration of the vegetable or fruit tissues or it may be imposed by flushing the pack with a suitable gas mixture. Although the future may see an expansion of MAP of these products it is true that MAP has severe limitations. Microorganisms of public health significance can multiply on vegetable tissues stored under MAP (Berrang *et al.*, 1989a, 1989b), but potentially the most serious problem is the enhanced respiration rate of damaged vegetable and fruit tissues. This can cause overmodification of the gaseous atmosphere within the pack, leading to anaerobic respiration of the vegetable and fruit tissues and the development of associated taints. It also raises the spectre of the possible growth and toxin production by anaerobic bacteria such as *Clostridium botulinum*.

Close matching of the permeability characteristics of the packaging material and the respiration rates of the product is essential, therefore, if overmodified atmospheres are to be avoided. Huxsoll and Bolin (1989) emphasised that the optimum concentrations of O_2 and CO_2 must be established for each commodity and for each kind of degradative reaction, and be matched with the packaging material, the permeability of which is affected by storage temperature, polymer type, thickness and the surface area of the material available for gaseous exchange.

Interest in 'active' packaging may grow and an attempt may be made to address some of the difficulties encountered in packaging respiring foods. 'Active' films modify the composition of gas within a pack by chemical reaction and so create and maintain the correctly poised atmosphere (Ronk *et al.*, 1989). For example, potassium permanganate has been used to absorb ethylene, calcium hydroxide to absorb CO_2, and O_2 scavengers based on the oxidation of ascorbic acid or ferrous compounds have also been available (Barmore, 1987). Although potentially useful, these films must be used cautiously. Chemical contamination of the fruit or vegetable tissue must be avoided, and it must be remembered that the capacity of the film to absorb gas is finite and the atmosphere will not be controlled once the active chemical agents are exhausted.

Microperforated films contain small pores, which allow mass transfer of gases to take place, so that movement through the film is not solely dependent upon diffusion. They can allow equilibrium concentrations of gases to be established in the case of rapidly respiring tissues, but their use tends to be somewhat by 'trial and error'.

Perhaps what all of this has identified as an urgent future requirement for these products is a comprehensive mathematical model encompassing tissue respiration rates and film permeabilities such that the composition

of the gaseous atmosphere of these packs can be controlled reliably and safely. Future market trends will almost certainly see the introduction of products that are predominantly or solely fruit tissues. The technical difficulties in the manufacture of these products are great, but some producers are already trying out attractive packs of fruit pieces.

References

Adams, M.R., Hartley, A.D. and Cox, J.L. (1989) Factors affecting the efficacy of washing procedures used in the production of prepared salads. *Food Microbiology*, **6**, 69–77.

Ahvenainen, R., Skyttä, E. and Kivikataja, R-L. (1990) The influence of modified atmosphere packaging on the quality of selected ready-to-eat foods. *Food Science and Technology: Lebensmittel-Wissenschaft & Technologie*, **23**, 139–48.

Anon (1990) Statutory Instrument No. 1431. Food. *Food Hygiene (Amendment) Regulations*. HMSO, London.

Babic, I., Hilbert, G., Nguyen-The, C. and Guiraud, J. (1992) The yeast flora of stored ready-to-use carrots and their role in spoilage. *International Journal of Food Science and Technology*, **27**, 473–84.

Baird-Parker, A.C. (1980) Organic acids, in *Microbial ecology of foods. Vol. 1. Factors affecting life and death of microorganisms*, International Commission on Microbiological Specifications for Foods, Academic Press, London, New York, pp. 126–35.

Barmore, C.R. (1987) Packing Technology for fresh and minimally processed fruits and vegetables. *Journal of Food Quality*, **10**, 207–17.

Baumgart, J. and Hauschild, G. (1980) Enfluß von weinsäure auf die Haltbarkeit von feinkost-salaten. *Fleischwirtsch*, **60**(5), 1052–6.

Baumgart, J., Hippe, H. and Weber, B. (1984) Verderb pasteurisierter feinkostsalate durch *Clostridien. Chemie Mikrobiologie Technologie der Lebensmittel*, **8**, 109–14.

Baumgart, J., Weber, B. and Hanekamp, B. (1983) Mikrobiologisch stabilität von feinkosterzeugnissen. *Fleischwirtschaft*, **63**(1), 93–4.

Berrang, M.E., Brackett, R.E. and Beuchat, L.R. (1989a) Growth of *Aeromonas hydrophila* on fresh vegetables stored under a controlled atmosphere. *Applied and Environmental Microbiology*, **55**(9), 2167–71.

Berrang, M.E., Brackett, R.E. and Beuchat, L.R. (1989b) Growth of *Listeria monocytogenes* on fresh vegetables stored under controlled atmosphere. *Journal of Food Protection*, **52**(10), 702–5.

Bodansky, M. (1928) Lipoid solubility, permeability and hemolytic action of the saturated fatty acids. *Journal of Biological Chemistry*, **79**, 241–55.

Bolin, H.R. and Huxsoll, C.C. (1991) Effect of preparation procedures and storage parameters on quality retention of salad-cut lettuce. *Journal of Food Science*, **56**(1), 60–7.

Bolin, H.R., Stafford, A.E., King, A.D. Jr. and Huxsoll, C.C. (1977) Factors affecting the storage stability of shredded lettuce. *Journal of Food Science*, **42**(5), 1319–21.

Bonestroo, M.N., Kusters, B.J.M., de Wit, J.C. and Rombouts, F.M. (1993) The fate of spoilage and pathogenic bacteria in fermented sauce-based salads. *Food Microbiology*, **10**, 101–11.

Boyar, M.M., Kilcast, D. and Dodson, A.G. (1985) Physico-chemical changes in stored coleslaw. *Leatherhead Food R.A. Research Report*, No. 502.

Brackett, R.E. (1987) Microbiological consequences of minimally processed fruits and vegetables. *Journal of Food Quality*, **10**, 195–206.

Brocklehurst, T.F. (1984) A delicatessen problem. *Food Manufacture*, **April**, 65 and 67.

Brocklehurst, T.F. and Lund, B.M. (1984) Microbiological changes in mayonnaise-based salads during storage. *Food Microbiology*, **1**, 5–12.

Brocklehurst, T.F. and van Bentem, E. (1990) Packed freshness at your service. *Food Science and Technology Today*, **4**(3), 156–8.

Brocklehurst, T.F., White, C.A. and Dennis, C. (1983) The microflora of stored coleslaw and factors affecting the growth of spoilage yeasts in coleslaw. *Journal of Applied Bacteriology*, **55**, 57–63.

Brocklehurst, T.F., Zaman-Wong, C.M. and Lund, B.M. (1987) A note on the microbiology of retail packs of prepared salad vegetables. *Journal of Applied Bacteriology*, **63**, 409–15.

B.S.I. (1980) British Standards Institute, *Methods for Sensory Analysis of Food, Part 1*, BS 5929, BSI, London.

Buick, R.K. and Damoglou, A.P. (1989) Effect of modified atmosphere packaging on the microbial development and visible shelf life of a mayonnaise-based vegetable salad. *Journal of the Science of Food and Agriculture*, **46**, 339–47.

Carlin, F., Nguyen-The, C., Cudennec, P. and Reich, M. (1989) Microbiological spoilage of 'ready-to-use' grated carrots. *Science des Aliments*, **9**, 371–386.

Carlin, F., Nguyen-The, C., Chambroy, Y. and Reich, M. (1990) Effects of controlled atmospheres on microbial spoilage, electrolyte leakage and sugar content of fresh 'ready-to-use' grated carrots. *International Journal of Food Science and Technology*, **25**, 110–19.

Cerny, G. and Hennlich, W. (1983) Microbial stability of meat-salads at ambient temperatures. Part 2: Pasteurization of heat-sensitive mayonnaise with or without addition of preservatives. *Internationale Zeitschrift für Lebensmittel-Technologie und Verfahrenstechnik*, **7**, 610–16.

Chen, L.M. and Peng, A.C. (1980) Effect of acid dip on the shelf life of coleslaw. *Journal of Food Science*, **45**, 1556–8.

Christiansen, L.N. and King, N.S. (1971) The microbial content of some salads and sandwiches at retail outlets. *Journal of Milk and Food Technology*, **34**(6), 289–93.

CIMSCEE (1985) *Code for the Production of Microbiologically Safe and Stable Emulsified and Non-emulsified Sauces Containing Acetic Acid*, Comité des Industries des Mayonnaise et Sauces Condimentaires de la Communauté Economique Européenne.

Collins, M.A. (1982) Investigations on some factors affecting the keeping quality of coleslaw. *Record of Agricultural Research*, **30**, 53–60.

Corry, J.E.L., Walker, A.K. and Jarvis, B. (1980) The storage of perishable dairy-type products. Part I: Coleslaw salad, cottage cheese, strawberry yoghurt and pasteurised double cream. *Leatherhead Food R.A. Research Report*, No. 335.

Davies, A.M.C. and Brocklehurst, T.F. (1986) Near infrared reflectance analysis of oil concentration in an emulsion: a study of oil and water migrations in a mayonnaise-based salad. *Journal of the Science of Food and Agriculture*, **37**, 310–16.

Debevere, J.M. (1987) The use of buffered acidulant systems to improve the microbiological stability of acid foods. *Food Microbiology*, **4**, 105–14.

Dennis, C. and Buhagiar, R.W.M. (1980) Yeast spoilage of fresh and processed fruits and vegetables, in *Biology and Activities of Yeasts* (eds F.A. Skinner, S.M. Passmore and R.R. Davenport), Academic Press.

Dziezak, J.D. (1988) Monsanto's new product extends produce freshness. *Food Technology*, **September**, 98.

Eklund, T. (1983) The antimicrobial effects of dissociated and undissociated sorbic acid at different pH levels. *Journal of Applied Bacteriology*, **54**, 383–9.

Fowler, J.L. and Clark, W.S. Jr. (1975) Microbiology of delicatessen salads. *Journal of Milk and Food Technology*, **38**(3), 146–9.

Galvin, P.A. (1991) Pasteurized salads using ingredient blend retain fresh flavor. *Food Technology*, June, 110.

Garg, N., Churey, J.J. and Splittstoesser, D.F. (1990) Effect of processing conditions on the microflora of fresh-cut vegetables. *Journal of Food Protection*, **53**(8), 701–3.

Geeson, J.D., Brocklehurst, T.F. and Griffiths, N. (1987) Be prepared. *Food*, **February**, 49–53.

Goepfert, J.M. (1980) Vegetables, fruits, nuts and their products. in *Microbial Ecology of Foods. Vol. 2. Food Commodities*, International Commission on Microbiological Specifications for Foods, Academic Press, London, New York, pp. 606–42.

Gordon, N.E. and Reid, E.E. (1922) The solubility of liquids in liquids. The partition of the lower acids, particularly formic, between water and various organic solvents. *Journal of Physical Chemistry*, **26**, 773–89.

Goupy, P. (1989) Le brunissement enzymatique de la feuille de Scarole (*Cichorum endiva*):

composés phénolique et enzymes d'oxydation des feuilles chlorophyllienes et étiolées. *Ph.D. thesis*, Université des Sciences et Techniques du Languedoc, Montpellier.

Greenwood, M.H., Coetzee, E.F.C., Ford, B.M., Gil, P., Hooper, W.L., Matthews, S.C.W., Patrick, S., Pether, J.V.S. and Scott, R.J.D. (1975) The bacteriological quality of selected retail, ready-to-eat food products. *Environmental Health*, **93**(8), 208–11.

Hankin, L. and Ullman, W.W. (1969) Application of the oxidase test to refrigerated delicatessen foods. *Journal of Milk and Food Technology*, **32**, 122–5.

Harris, N.H., Martin, S.R. and Ellias, L. (1975) Bacteriological quality of selected delicatessen foods. *Journal of Milk and Food Technology*, **38**, 759–61.

Heaton, E.K., Boggess, T.S. Jr. and Li, K.C. (1969) Processing refrigerated fresh peach slices. *Food Technology*, **23**, 96–100.

Hilliam, M.A. (1986) *Chilled foods in the UK – second edition*, Leatherhead Food R.A. Information Group Services (Market Information Service), Food Market Update No. 14.

Holtzapffel, D. and Mossel, D.A.A. (1968) The survival of pathogenic bacteria in, and the microbial spoilage of, salads, containing meat, fish and vegetables. *Journal of Food Technology*, **3**, 223–39.

Horne, A.M.L. (1989) *Chilled foods in the UK – third edition*, Leatherhead Food R.A. Information Group Services (Market Intelligence Section), Food Market Update No. 33.

Huxsoll, C.C. and Bolin, H.R. (1989) Processing and distribution alternatives for minimally processed fruits and vegetables. *Food Technology*, **February** 124–8.

IFST (1990) *Guidelines for the Handling of Chilled Foods*, 2nd edn, Institute of Food Science and Technology, London.

Isenberg, F.M.R. (1979) Controlled atmosphere storage of vegetables. *Horticultural Review*, **1**, 337–94.

Kaufman, J. and Lutz, J.M. (1954) Lengthening the shelf life of packaged coleslaw. *Pre-Pack-Age*, **8**, 23–6.

King, A.D. Jr. and Bolin, H.R. (1989) Physiological and microbiological storage stability of minimally processed fruits and vegetables. *Food Technology*, **February**, 132–5.

King, A.D. Jr., Michener, H.D., Bayne, H.G. and Mihara, K.L. (1976) Microbial studies on shelf life of cabbage and coleslaw. *Applied and Environmental Microbiology*, **31**(3), 404–7.

Kirsop, B.H. and Brocklehurst, T.F. (1982) The spoilage of mayonnaise-based delicatessen salads. *Process Biochemistry*, **September/October**, 9–14.

Leo, A., Hansch, C. and Elkins, D. (1971) Partition coefficients and their uses. *Chemical Reviews*, **71**(6), 525–616.

Lueck, E. (1980) *Antimicrobial Food Additives: Characteristics, Uses, Effects*, Springer-Verlag, Berlin, Heidelberg, New York.

MAFF (1992) *Food Micromodel*, Ministry of Agriculture, Fisheries and Food, London.

Manvell, P.M. and Ackland, M.R. (1986) Rapid detection of microbial growth in vegetable salads at chill and abuse temperatures. *Food Microbiology*, **3**, 59–65.

McKinley, T.W., Henning, W.C. and McCroan, J.E. (1974) *Staphylococcal* growth and enterotoxin production in chicken and chicken salad. *Association of Food and Drug Officials Quarterly Bulletin*, **38**, 56.

McLachlan, A. and Stark, R. (1985) Modified atmosphere packaging of selected prepared vegetables. *Campden Food Preservation Research Association Technical Memorandum*, No. 412.

Myers, R.A. (1989) Packaging considerations for minimally processed fruits and vegetables. *Food Technology*, February, 129–31.

Nguyen-The, C. and Prunier, J.P. (1989) Involvement of pseudomonads in deterioration of 'ready-to-use' salads. *International Journal of Food Science and Technology*, **24**, 47–58.

Norberg, A.P. and Åkerstrand, K. (1980) Hållbarhetstider för färdigförpackade sallader. *Vår Föda*, **1**, 25–30.

O'Beirne, D. and Ballantyne, A. (1987) Some effects of modified-atmosphere packaging and vacuum packaging in combination with antioxidants on quality and storage life of chilled potato strips. *International Journal of Food Science and Technology*, **22**, 515–23.

Pace, P.J. (1975) Bacteriological quality of delicatessen foods: are standards needed? *Journal of Milk and Food Technology*, **38**(6), 347–53.

Ponting, J.D., Jackson, R. and Watters, G. (1972) Refrigerated apple slices: preservative effects of ascorbic acid, calcium and sulfites. *Journal of Food Science,* **37**, 434–6.

Priepke, P.E., Wei, L.S. and Nelson, A.I. (1976) Refrigerated storage of prepackaged salad vegetables. *Journal of Food Science*, **41**, 379–82.

Ranken, M.D. (1988) *Food Industries Manual*, 22nd edn, Blackie Academic & Professional, Glasgow.

Roberts, D. (1990) Sources of infection: food. *The Lancet*, **8719**, 859–61.

Robinson, J.E., Browne, K.M. and Burton, W.G. (1975) Storage characteristics of some vegetables and soft fruits. *Annals of Applied Biology*, **81**, 399–408.

Robinson, R.A. and Stokes, R.H. (1959) *Electrolyte Solutions*, Butterworths, London.

Rolle, R.S. and Chism, G.W. (1987) Physiological consequences of minimally processed fruits and vegetables. *Journal of Food Quality*, **10**, 157–77.

Ronk, R.J., Carson, K.L. and Thompson, P. (1989) Processing, packaging and regulation of minimally processed fruits and vegetables. *Food Technology*, **February**, 136–9.

Rose, S.A. (1984) Studies of the microbiological status of prepacked delicatessen salads collected from retail chill cabinets. *Campden Food Preservation Research Association, Technical Memorandum*, No. 371.

Rumpf, G. and Hansen, H. (1973) Gaschromatographische Bestimmung löslicher Inhaltstoffe in 'Controlled atmosphere' – gelagerten Möhren. *Gartenbauwissenschaft*, **38**, 281–5.

Shapiro, J.E. and Holder, I.A. (1960) Effect of antibiotic and chemical dips on the microflora of packaged salad mix. *Applied Microbiology*, **8**, 341–5.

Sizmur, K. and Walker, C.W. (1988) Listeria in prepacked salads. *The Lancet*, **8595**, 1167.

Sugiyama, H. and Yang, K.H. (1975) Growth potential of *Clostridium botulinum* in fresh mushrooms packaged in semi-permeable plastic film. *Applied Microbiology*, **30**, 964–9.

Tamminga, S.K., Beumer, R.R., Kiejbets, M.J.H. and Kampelmacher, E.H. (1978) Microbial spoilage and development of food poisoning bacteria in peeled completely or partly cooked vacuum packaged potatoes. *Archiv fur Lebensmittelhygiene*, **29**, 215–19.

Terry, R.C. and Overcast, W.W. (1976) A microbiological profile of commercially prepared salads. *Journal of Food Science*, **41**, 211–13.

Tunaley, A. and Brocklehurst, T.F. (1982) A study on the shelf-life of coleslaw. *Chilled Foods*, **November/December**, 12–13.

Tunaley, A., Brownsey, G. and Brocklehurst, T.F. (1985) Changes in mayonnaise-based salads during storage. *Food Science and Technology: Lebensmittel-Wissenschaft & Technologie*, **18**, 220–4.

Tuynenburg Muys, G. (1971) Microbial safety in emulsions. *Process Biochemistry*, **6**(6), 25–8.

von Schelhorn, M. (1951) Control of microorganisms causing spoilage in fruit and vegetable products. *Advances in Food Research*, **3**, 429–83.

von Schelhorn, M. (1964) Investigations of the distribution of preservatives between fat and water in foods. *Fourth International Symposium Food Microbiology*, Goteburg, Sweden, 1964, 139–144.

Wiberg, A.C., Larsson, B., Movitz, J. and Akerstrand, K. (1983) Hållbarhetstider för färdigförpackade sallader. *Vår Föda*, **35**, 404–16.

Williams, A.P. (1990) Chilled combined foods and chilled meals, in *Chilled Foods. The state of the art* (ed. T.R. Gormley), Elsevier Applied Science, London and New York, pp. 225–43.

Young, J.N. (1984) Delicatessen foods in the UK. *Leatherhead Food R.A., Food Market Update*, No. 33.

7 Chilled yogurt and other dairy desserts

M. LEWIS and R.H. DALE

7.1 Introduction

For many years the production of short-life perishable food products was organised and carried out on a regional or local level. This enabled products to be sold within a very short period following manufacture. However, since the Second World War a major revolution has taken place within the food industries of Europe, the USA and Japan. This has occurred in the chilled, short-life dairy products sector in particular.

Modern marketing methods and techniques have created ever increasing mass markets with an apparently insatiable appetite for new and novel products. The drive for increasing the efficiency of production plants in order to reduce costs and increase profits has led to a centralisation of production units. Major improvements in the ability of manufacturers and retailers to transport refrigerated products over long distances coupled with the lowering of trade barriers within the European Community have created export opportunities. All this now means that dairy desserts once considered perishable within very short periods are required for consumption many days after their manufacture. This tremendous change within the market both in volume and requirement has created immense technical problems and has led to a quiet revolution in the field of food technology.

Ensuring the safety of these products has of course been paramount, but to underwrite the commercial success it has been equally important to ensure that other product parameters remain good. Indeed, the sensory, visual and physical characteristics should exhibit the same quality of freshness at the end of the product's life as at the beginning.

This requirement for freshness (often associated by the consumer with healthiness and wholesomeness) together with the safety requirements have taken place in an environment where the removal of 'artificial' preservatives and other additives was also demanded. The challenge created for the food and dairy technologists has been enormous.

In order for the public to be confident of the quality of these products, the Government introduced mandatory date coding. Initially this was adopted by the food industry in the form of 'sell-by' dates. However, recent changes in UK and EC legislation require 'best before' dates for non-perishable products and a more definitive 'use-by' date for micro-

biologically unstable products such as dairy desserts. This legislation also requires manufacturers to be able to justify the codes which are applied to the products if requested to do so by the enforcement authorities. Therefore, it has been necessary for the food technologist, not only to extend the life of the products, but also to improve the methods by which the shelf life is determined.

This chapter will review many aspects of shelf life associated with dairy desserts, not in complicated scientific terms but in the practical language of the dairy industry. It will attempt to categorise dairy desserts into broad groupings and discuss key factors affecting shelf life from raw materials through to the consumer.

7.2 Products, product groups and characteristics

Over the last ten years, the sale of yogurt, fromage frais and other desserts has shown a steady growth, benefiting from market segmentation and the healthy eating trend. More recently, there has been an increasing trend for the more indulgent products containing higher fat levels, exotic fruits and the use of 'Bio' cultures.

The different varieties and percentages of sales by volume of yogurts, fromage frais and traditional desserts are shown in Figures 7.1–7.3.

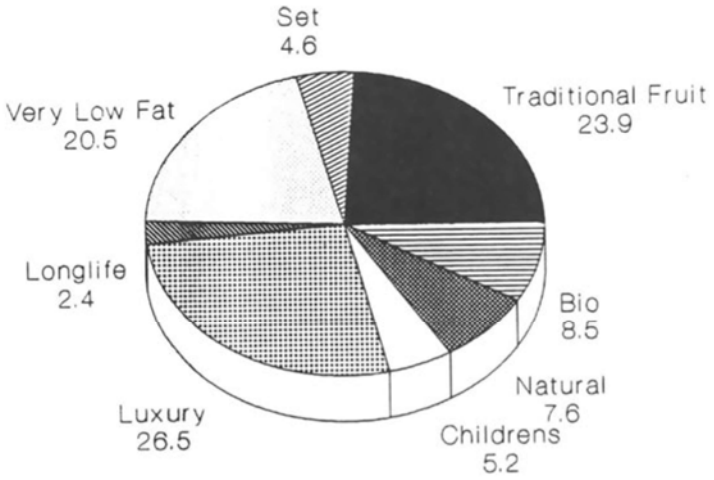


Figure 7.1 Yogurt – percentage of total sales.

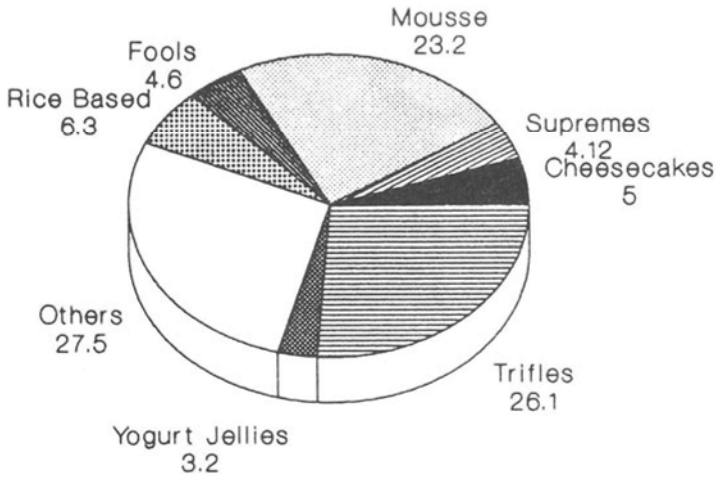


Figure 7.2 Traditional desserts – percentage of total sales.

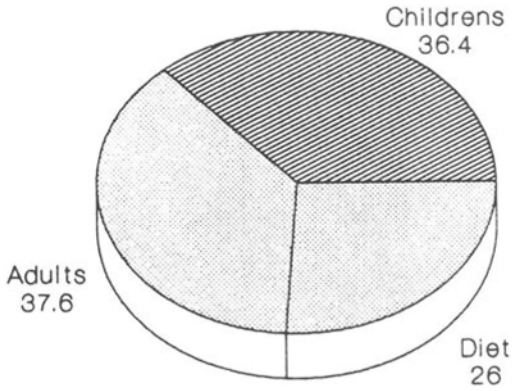


Figure 7.3 Fromage frais – percentage of total sales.

7.2.1 Product groups

For shelf life evaluation the products are classified into two main groups:

1. cultured products
2. desserts (un-fermented/blends)

The manufacture of cultured products involves the controlled use of lactic acid producing microorganisms for prescribed time and temperature com-

binations to achieve a final product with the desired characteristics of viscosity, texture, mouthfeel, flavour and acidity.

The desserts are either simple products such as custards and jellies or complex products including trifles, mousses and cheesecakes which are a mixture of textures, taste and acidity levels. General classifications of chilled yogurts, soft cheeses and desserts are given in Figures 7.4, 7.5 and 7.6.

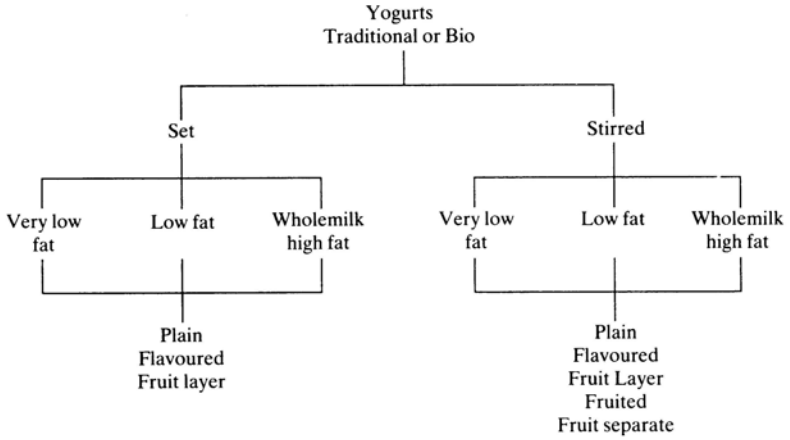


Figure 7.4 General classifications of chilled yogurts.

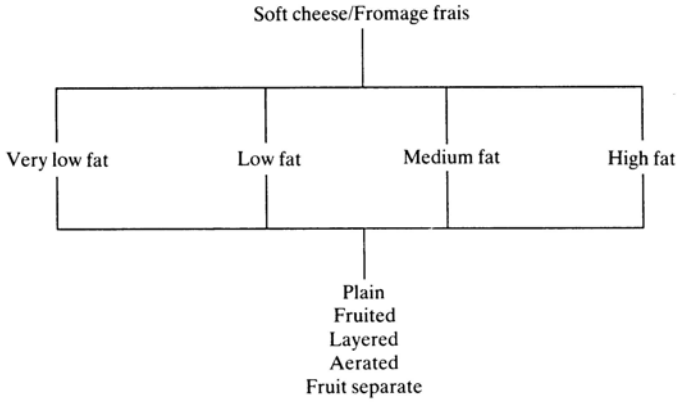


Figure 7.5 General classifications of chilled soft cheeses.

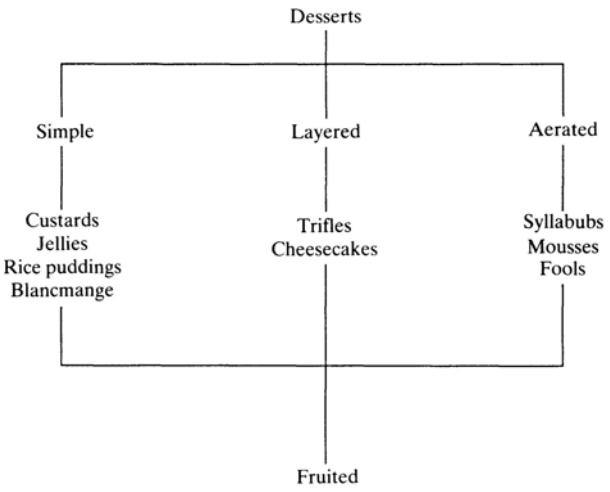


Figure 7.6 General classifications of chilled desserts.

7.2.2 Product characteristics

7.2.2.1 Yogurts

(a) Stirred yogurt. The texture should be smooth with a glossy appearance, thick and almost pourable, but must not be grainy or nodulated. The colour of natural yogurt should be creamy white. If fruited, it should represent the colour of the fruit without being too bright. The typical yogurt flavour – slightly acidic, clean, fresh with the acetaldehyde note, should be distinguishable and complementary to the fruit flavour.

(b) Bio yogurts. The Bio yogurts should be milder and creamier in taste than the traditional yogurts, but of similar colour and texture.

(c) Set yogurts. Set yogurts should have a glossy surface appearance without excessive whey. The texture is smooth and almost junket-like, giving a clean cut when spooned.

7.2.2.2 Fromage frais. Natural low fat fromage frais is milky white in colour, has a smooth texture with a spreadable consistency. It is clean and mildly acidic in flavour with no appearance of syneresis.

7.2.2.3 Desserts

(a) Layered. Generally the layered products will have a spectrum of textures. Taste will range from sweet to acidic, strong to bland and the colours and flavours should complement the individual components. Cake and biscuit layers should retain their characteristic crunchy or open texture and not become wet and soggy.

(b) Custards. The texture should be smooth and thick with a glossy surface, but not gelatinous or grainy.

(c) Jellies. The gels should not be too brittle, but firm with 'melt-in-the-mouth' characteristics and a good fruity flavour.

(d) Mousses. Mousses may be whipped for varying periods to obtain either high or low overruns depending on the final textural characteristics required. In all cases a mousse should have uniform air cells. It should retain its texture and overrun without collapsing during its shelf life.

7.3 Factors affecting shelf life

Commercially the shelf life of a product may be defined as the number of days after production that the product can be consumed whilst still remaining safe, retaining its quality appeal, and meeting customer expectations. In other words, it should remain microbiologically safe and organoleptically acceptable within its stated shelf life.

To evaluate the shelf life of any product it is first necessary to identify which characteristics of the ingredients, the process and the storage conditions are responsible for, or will have an influence on, its shelf life.

The life of short chilled dairy desserts is influenced by:

- raw materials;
- product formulation;
- processing parameters;
- implementation of Good Manufacturing Practice;
- filling and packaging;
- storage and distribution;
- consumer usage and handling.

Measurement, monitoring and control of the above are of paramount importance in the evaluation process. The point at which the product becomes unacceptable either organoleptically or microbiologically, whichever manifests itself first, is the ultimate end point from which the life can be established.

Table 7.1 Raw materials commonly used in the manufacture of chilled yogurt and other dairy desserts

Yogurt	Soft cheese/ fromage frais	Desserts
Milk	Milk	Milk
Cream	Cream	Cake/sponge/biscuits
Sugar	Sugar	Stabiliser: gelatine, starch, pectin, gums
Cultures	Cultures	Sugar
Milk concentrates	Fruit/fruit conserves	Fruit/fruit conserves
Milk powders	Flavours	Cream
Fruit/fruit conserves	Colours	Flavours
Stabilisers		Colours
Flavours		Decoration: cherries, nuts, vermicelli
Colours		

7.3.1 Raw materials

The raw materials most likely to be used for the production of yogurt, fromage frais and desserts are given in Table 7.1. All the listed ingredients introduce microorganisms and chemicals which may affect the quality of the final product. Partnerships with approved suppliers and agreed specifications will help the dessert manufacturer to consistently supply a product which remains acceptable within the determined life. Changes in source and supply of these ingredients will result in a variation of factors which influence shelf life and is not to be recommended.

7.3.1.1 Milk. This ingredient, which is common to all the products, is variable in all the main constituents – protein, lactose, fat and in the microbiological flora.

The variability occurs between different breeds of cattle, different geographical regions and is seasonal. The control of the type and level of microorganisms, together with the monitoring of the protein content, is essential as these significantly affect the texture and stability of the final product.

The microorganisms can gain access to the milk from the cow, personnel or equipment used during milking, or during transportation to and storage at the processing dairy. To keep the microbiological flora to a minimum it is essential to cool the milk to below 5°C directly after milking. This temperature should be maintained until the milk is processed at the manufacturing site.

Recent trends have been towards larger dairy units having milk collection every other day or even twice a week. This has encouraged dairy farmers to invest in more hygienic equipment and increased awareness of health and quality issues, but has increased the potential for microbial growth and enzyme activity.

Modern methods of manufacture, plus quality standards demanded by national legislation, EC Directives and the dairy industry in general, have ensured that the raw milk on receipt at the processing factory tastes good, has a low bacterial count and is free from impurities. This quality is maintained by heat processing followed by cooling to 5°C as soon as possible after receipt of the milk.

Milk used for the manufacture of the dairy products should therefore have low bacterial counts, no off-flavours and minimal enzymic degradation. Stock rotation and control of temperatures will help to ensure a good quality basic raw material for all short shelf life dairy products.

7.3.1.2 Cream. The quality of the cream will be dependent on the quality of the milk used for separation and the method of handling before and after pasteurisation. Being high in fat the cream is more susceptible to enzyme degradation from lipase which splits the triglycerides into fatty acids, mono and diglycerides and glycerol. This will result in extreme cases in a rancid taste being evident in the final product. Lipase is inactivated to a greater extent by pasteurisation. However, as many micro-organisms produce lipase, this can still be a problem if the cream is handled unhygienically after processing.

If milk is to be held for a prolonged period prior to separation it is often pasteurised immediately on receipt. Microbiological quality is monitored by testing for total viable count (TVC) and coliforms.

7.3.1.3 Concentrates. The two methods generally used for the concentration of milk solids are:

1. removal of water by evaporation;
2. removal of water by membrane filtration.

For both methods the quality of the concentrated milk is dependent on the quality of the raw milk used, and the handling techniques before and during processing.

The microbiological flora should be low in heat resistant bacteria (thermodurics) and low in spore formers. Chemically, milk which is to be evaporated must be heat stable in order to withstand the pre-heat treatment process.

After concentration, the temperature of storage and handling methods are critical to the microbiological quality. Depending on the rate of cooling and the concentration factor, lactose crystallisation may occur, which could adversely affect the flavour and textural characteristics of the final product.

Quality is monitored microbiologically by checking for spore formers and coliforms and chemically for fat, lactose, protein, total solids and pH.

7.3.1.4 Cultures. Culture management and the activity and viability of the organisms is vital to final product quality, and to the shelf life of fermented products.

Culture preparation and handling demands the highest standards of hygiene combined with attention to detail in the manufacturing techniques and in the selection of plant. The risk of airborne contamination by yeast, moulds, bacteria and bacteriophage must be eliminated.

The cultures, when used, must contain very high numbers of viable and active bacteria in the correct ratio to achieve the desired pH in the appropriate time.

The quality of the bulk culture is maintained by storage at below 5°C for a maximum of 48 hours. The quality is monitored by testing for yeasts, moulds, cell balance and culture activity.

For direct vat inoculation, frozen cell concentrates are used and it is essential that these are stored at very low temperatures and used in accordance with the manufacturer's instructions.

7.3.1.5 Fruit. After harvesting, fruit will remain acceptable for only a limited period of time. The time varies considerably by fruit type and variety, country of origin, harvesting methods and the method of storage employed by the grower.

Spoilage is caused mainly by microbiological activity (especially when fruit has been damaged), and chemical reactions catalysed by enzymes which occur naturally in the fruit.

To assure good quality fruit for further processing it is necessary to either destroy the factors responsible for spoilage or to inhibit them. This is achieved by either heat sterilisation (canning) or deep freezing. The processed fruits (canned or frozen) are all regarded as raw materials to produce conserves for inclusion in dairy desserts.

A major area of concern, not directly associated with shelf life but of paramount importance, is the presence of pesticides and other agrochemicals, which are used during growth and post-harvest storage. All fruits should be screened for these. They must be controlled within the limits specified in the legislation governing agrochemical residues.

7.3.1.6 Other ingredients. As for any of the other raw materials used, the source of the ingredient, approval of supplier, the identification of critical control points (CCPs), and hygiene standards are all important factors in the shelf life of the final product.

7.3.2 Processing

An understanding of the synergistic and antagonistic reactions that take place with different processing methods when a variety of functional

ingredients are used is necessary when a formulation is being developed. This may have a very important influence on the stability of the final product.

7.3.2.1 Yogurt. Having specified the microbiological, physical and chemical qualities and the accepted tolerances of the ingredients, the basic yogurt mix is subjected to a relatively severe heat treatment. This achieves four objectives:

1. Destruction of any undesirable organisms including pathogens.
2. Formation of physico-chemical complexes and denaturation of the whey proteins which ultimately affect the texture and water binding capacity of the coagulum.
3. Reduction of dissolved oxygen.
4. Formation of amino acids, peptides and other factors which enhance the growth of the culture organisms.

After addition of the culture, which is traditionally thermophilic, it is essential that the organisms (typically *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus salivarius* subsp. *thermophilus*) have ideal conditions in which to grow, i.e.: optimum temperature and a medium with all the desired factors, but without any inhibitory substances. The influence of cultures on final product quality and their susceptibility to outside influences must not be underestimated.

After fermentation to the desired pH the yogurt is cooled to below 20°C and often stored for a short period prior to filling.

It is essential that the pumps, heat exchangers, pipelines and storage tanks are cleaned and sterilised before use. Samples of the yogurt base from each batch should be checked for viscosity, texture, flavour and the presence of coliforms, yeasts and moulds. Coliforms will not normally survive in the low pH medium, but if initially present will indicate poor or inadequate cleaning of the plant. A typical manufacturing scheme for yogurts is given in Figure 7.7.

7.3.2.2 Fromage frais. Many of the manufacturing principles that apply to yogurt also apply to the manufacture of fromage frais. As with yogurt production, the solids level of the milk is increased and the mix is heat treated and held before cooling to incubation temperatures.

However, the lactic acid producing cultures used are different. These being mesophilic organisms, they require a lower incubation temperature and give fromage frais its distinct flavour and texture. As the incubation temperature is much lower than that for yogurt, and could also be suitable for the growth of undesirable organisms, great care must be taken in ensuring that the vats and associated equipment are all clean and sterile.

After incubation the coagulum is cooled to inactivate the cultures and

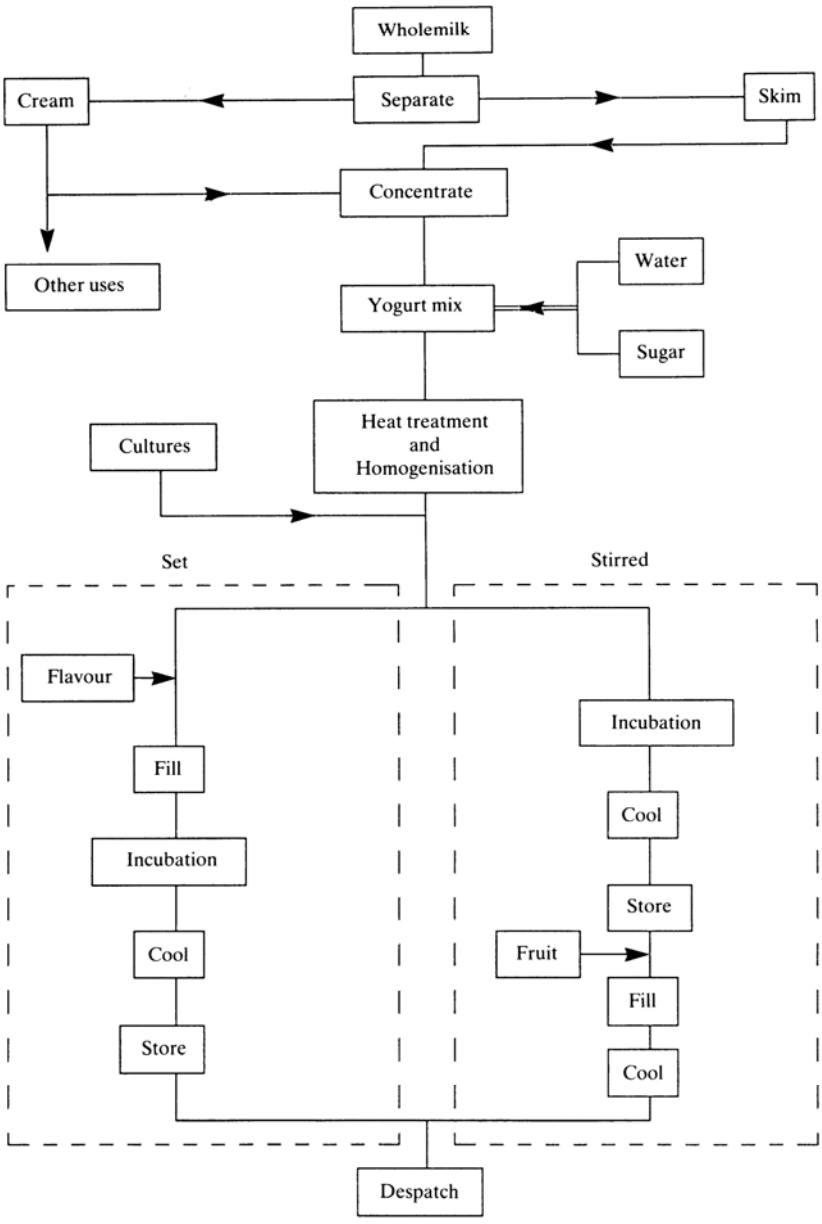


Figure 7.7 A typical manufacturing scheme for yogurts.

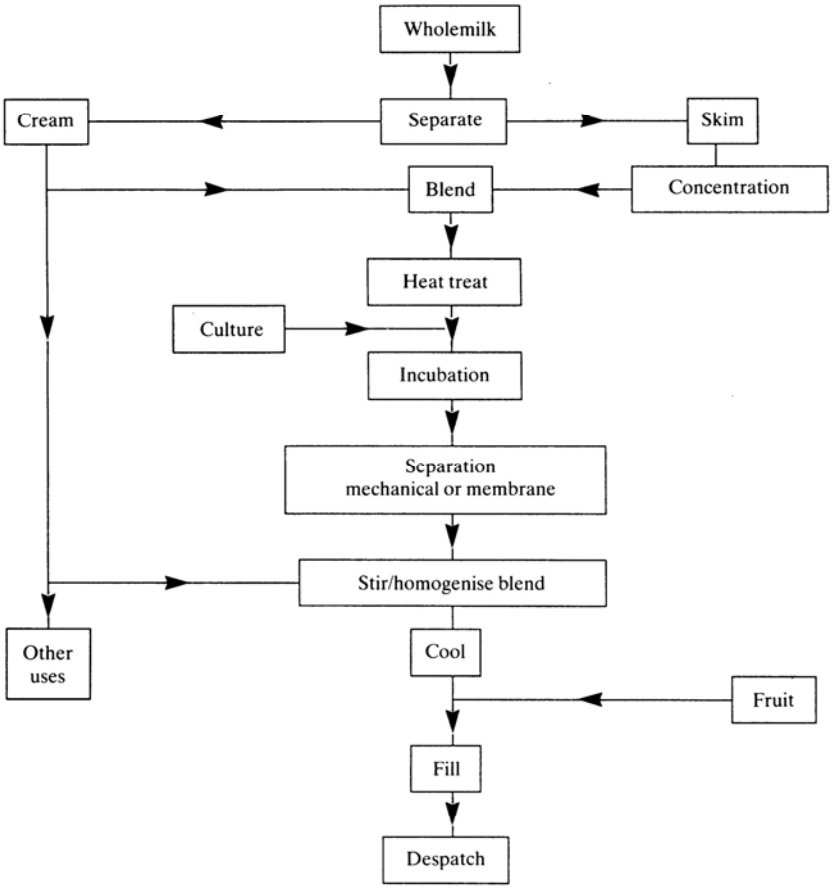


Figure 7.8 The manufacturing process for fromage frais.

prevent a further decrease in pH. At this stage, if the desired texture and viscosity have not been optimised, a further concentration of total solids is necessary. This is achieved by firstly re-heating the mix followed by either mechanical separation or membrane filtration.

Having achieved the correct viscosity and total solids, cream can be blended into the base (i.e. the plain curd, also known as 'fromage blanc') to give the required fat level. Fruit is normally added prior to filling.

At each critical stage of the process samples are taken and checked for the presence of coliform, yeast and moulds. The final product is also checked for viscosity, texture and flavour. The manufacturing process for fromage frais follows the general scheme shown in Figure 7.8.

7.3.2.3 Desserts. Desserts range from the relatively simple jellies, mousses and custards to layered products such as trifles, cheese cakes and complex continental desserts such as tiramisu. This combination gives a variety of textures, tastes, colours and appearances. For shelf life evaluation it is important that these attributes are maintained through life, e.g. crunchy texture, stability of aeration, absence of syneresis and leaching of colour.

Microbiologically the desserts are more vulnerable to contamination from spoilage organisms which may include pathogens due to the more neutral pH of the product and increased handling.

Processing methods for individual components are relatively simple; a simplified trifle-making process is represented in Figure 7.9.

(a) Mousse. Traditionally a mousse is high in fat with a high overrun, and this foam must be stable for the duration of its shelf life. Modern trends however, are for low fat mousses.

The structure of a mousse is normally maintained by the use of stabilisers or whipping agents. With advancements in functional and novel ingredients different structures can be achieved ranging from a soft open texture with large air cells to a strong almost rubbery texture with very small air cells.

(b) Custards. The selective use of stabilisers and starches will ensure that the desired texture is achieved – ranging from creamy to light and short to gelatinous.

The starch and other hydrocolloids must be well dispersed and fully hydrated before being heat treated to the desired temperature. The time and temperature used must ensure that the starch is cooked and the custard is pasteurised. The product can either be filled hot, or if used in combination with other ingredients, cooled to a temperature slightly above the gelation point. This prevents damaging the structure of the other ingredients in the multi-layered product.

(c) Jellies. Gelatine can contain a relatively high level of spore formers and the processing conditions must ensure that these are destroyed. The critical area is the storage temperature of the mix prior to filling, or in the case of complex desserts before addition to the other components of the product. This temperature must be sufficiently high to prevent the growth of microorganisms, but must not adversely affect the colour and flavour of the jelly and other components.

The most important aspects of desserts manufacture are the implementation of good manufacturing practices, personal and plant hygiene, and training. Implementation of aseptic techniques during processing,

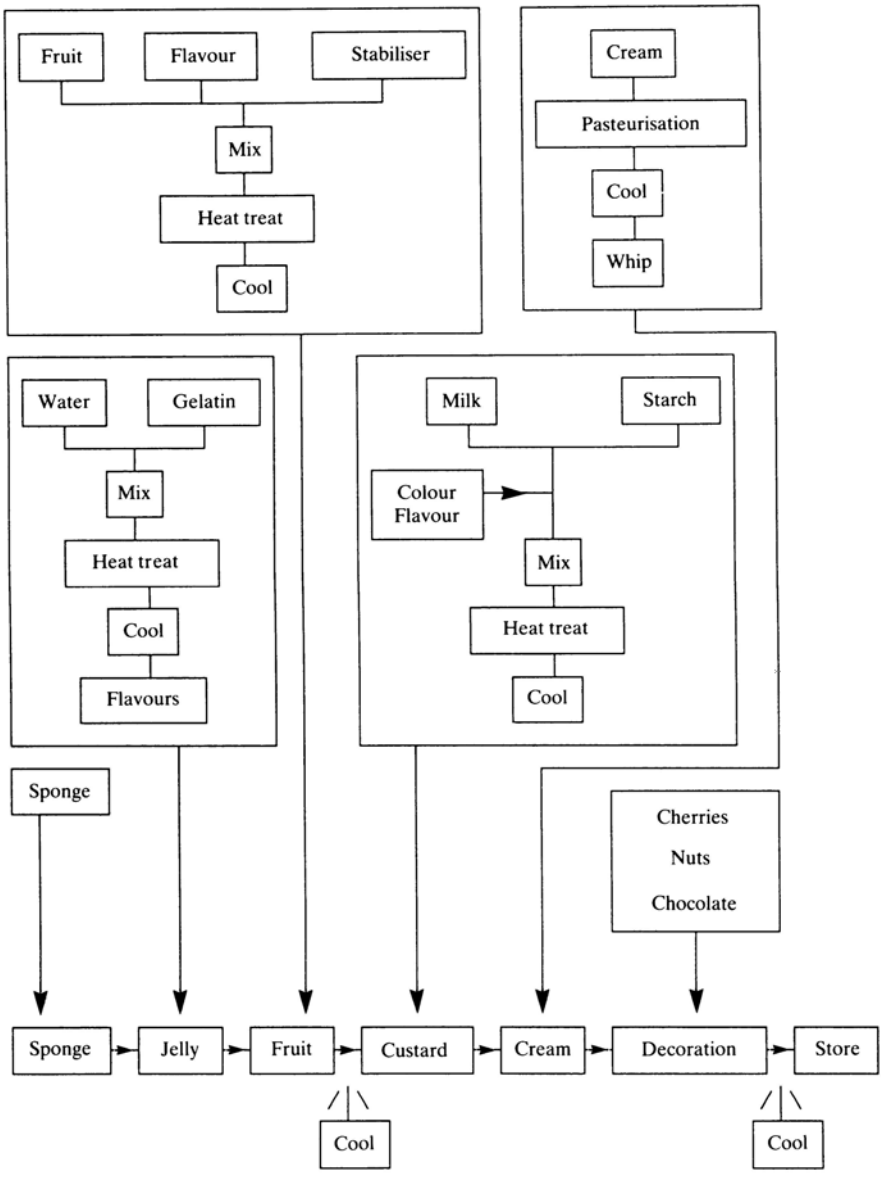


Figure 7.9 A simplified trifle-making process.

handling and filling is vital to ensure that the full shelf life potential of the product is realised. Critical control points should be identified and appropriate testing regimes be in place to ensure that the key standards are met.

7.3.2.4 Fruit conserves. These will be specific for the product in terms of flavour, viscosity, pH and colour. The conserve chosen will depend upon the pH level, sweetness, and the addition rate to the final product.

To produce a fruit conserve which is stable for use in dairy products and free from yeasts, moulds and other undesirable organisms, the mix should be heated to 85°C or more for several minutes.

The fruit conserve will contain stabilisers (starch, pectins, gums) to give the desired viscosity, enhance mouthfeel and ensure that an even distribution of the fruit throughout the mix is maintained. Sugar is added to improve flavour and in some cases reduce the water activity.

The heating process may damage the colour of the mix and the flavour profile of the fruit. Therefore, colour and flavouring is usually added aseptically at the end of the process.

It is important to note that the shelf life of the fruit conserve as an ingredient will have a bearing on the shelf life of the final product. The normal shelf life of the conserve is 6–8 weeks, however, the microbiological stability is often significantly greater. The limiting factors are the colour and flavour changes. Therefore, if a yogurt is to have a shelf life of 2 weeks, then the fruit conserve must be used at least 2 weeks before the end of its own shelf life.

For large-scale manufacture the fruit conserve is normally delivered in 800 kg–1000 kg stainless steel vessels, for smaller processing operations in 25 kg–40 kg poly bags. The methods adopted to fill these containers, the heat treatment given during processing and the positive release systems in place by the fruit supplier should ensure that the fruit conserves arrive at the processing factory free from any yeast and mould contamination.

The same standards of hygiene and handling of the container must be implemented at the processing factory when the fruit vessels are connected to, and disconnected from the blending station. Similarly the poly bags must be emptied into pre-sterilised vessels where plant hygiene is of paramount importance.

The fruit vessels may be used in production several times within the shelf life of the conserve. Each time the vessel is used a risk of contamination from yeast and mould occurs. To manage the risk factor, good manufacturing practices should be adopted and operators instructed on handling methods, food safety issues and hygiene.

A further safeguard is achieved by measuring the carbon dioxide level within the headspace of the conserve vessel before initial use and at each subsequent visit to the filling area. An increase in carbon dioxide level may indicate activity of yeasts and the vessel should be rejected.

7.3.3 Filling and packaging

The filling operation and choice of packaging materials are critical to the ability of almost all food products to achieve their potential shelf life. In the case of short shelf life products such as yogurt and dairy desserts, this part of the process is critical due to the relatively delicate physical nature and microbiological sensitivity of the products. The filling and packaging operation is the last direct contact that the manufacturer has with the product.

The incorrect choice of filling mechanism, poor hygiene practices and the inability of packaging materials to protect the product can result in premature shelf life failure and customer dissatisfaction. Therefore, all the effort put into the selection of raw materials and developing the correct processing conditions can be wasted by injudicious actions in the final stages of production.

7.3.3.1 Filling. The most important aspect of the filling operation with regard to shelf life is hygiene – the filler must be capable of being thoroughly cleaned and sterilised prior to the commencement of the filling operation. Failure to do this will inevitably result in, at best, a reduced shelf life of a product and, at worst, a food poisoning incident.

Most modern, high throughput fillers are capable of being fully cleaned in place. However, many older, small scale fillers need to be stripped down and manually cleaned. With this manual operation it is essential that the filler is reassembled with great care, and that a sterilising rinse is given prior to the commencement of the filling operation.

Most microbiological shelf life failure is caused by post-processing contamination at the filling stage either due to poor cleaning, poor design or environmental factors.

In the case of products such as yogurt and fromage frais which are of relatively low pH (<4.6) the most common spoilage organisms are yeasts. The yeasts involved in the spoilage of dairy products are commonly the lactose fermenting genera. However, due to the levels of sucrose incorporated into many products, other genera may also be found. Typical spoilage yeasts may be *Saccharomyces* and *Candida* spp. Moulds can also cause the premature spoilage of yogurts and fromage frais. However, as yeast and mould contaminations often occur together, it tends to be the production of gas by yeasts which is first noticed as a 'blowing' pack, and therefore, the yeast is identified as the spoilage organism.

The more neutral desserts (pH >4.6), whilst being subject to premature spoilage by yeasts and moulds, are also an ideal medium for bacterial growth. The bacteria most frequently found to contaminate desserts at the filling stage are members of the *Enterobacteriaceae* group, *Pseudomonas*

spp., and *Bacillus* spp. (in particular *B. cereus*) which is commonly associated with cream products.

Bacterial spoilage may take two forms:

1. The souring of products due to the production of acid and off-flavours.
2. The enzymic breakdown of the structure of products due to the activities of exo-enzymes.

7.3.3.2 Packaging. Packaging, both in design and material terms, can have a major influence on the shelf life of the product. Packaging fulfils a number of functions which may include:

- protection of the product from physical damage;
- protection of the product from the environment;
- protection of the product from changes in the environment;
- provision of attractive marketing designs to convey information including the date code to the consumer;
- presentation of the product in an easy to handle and store format for distribution to the retailer and consumer.

The packaging of product can therefore influence the shelf life in a number of ways:

(a) Microbiologically. Packaging can carry microorganisms, and therefore must be manufactured and stored hygienically to ensure a minimum microbial loading. This is particularly important in the case of preformed pots which must be stored in a clean, dry, pest-proof environment. Ideally the outer cases should only be removed prior to the containers being taken into the filling room.

For 'form-fill-seal' packaging which is wound on a spool, again the outer packaging should only be removed immediately prior to entering the filling room. Additionally a substantial amount of the reel should be discarded before the material is fed into the pot-forming chamber of the filler. Lidding materials should be treated similarly to minimise any microbiological contamination.

For heat sealed containers where the lid is bonded to the pot the most common sealing problem is caused by product contaminating the lip of the pot and interfering with the bonding process.

'Snap-on' lids must be produced to tight tolerances to ensure an effective seal is obtained. Often a plastics tamper evident ring or other secondary packaging will assist in maintaining the integrity of the pack.

The seal of the pack must be secure in order to exclude environmental contamination, particularly during the cooling phase when a partial vacuum may be formed.

(b) Organoleptically. The most common 'off-flavour' associated with yogurts and dairy desserts which develops with time is caused by the oxidation of the milk fat. Flavour degradation also occurs with time and very often is an oxidative change.

Utilising the correct type of packaging material which reduces the level of oxygen permeability and light penetration can help to minimise changes induced by these environmental factors.

In neutral, or near neutral pH desserts, the shelf life is significantly shorter due to microbiological considerations, and therefore, oxidation is unlikely to be critical.

In some high fat desserts, with fat levels in excess of 5%, the flavour changes due to oxidation may be the determining factor.

(c) Visual. As with flavours, colour fade or change may occur over a prolonged period. This is particularly noticeable with natural red colours such as beetroot red (betanin). Many factors can influence colour change, including oxygen, pH and the presence of sulphur dioxide, which may be carried over in small quantities from any fruit that is added to the yogurt or desserts.

7.3.4 Storage and distribution

All foods, and dairy desserts are no exception, may spoil during storage and distribution. In general this may be due to:

- growth of microorganisms;
- biochemical and chemical changes such as oxidation, rancidity development and moisture migration;
- attacks by vermin, birds or other pests.

Physical damage of products is prevented by enforcing good standards of storage, handling and pest control within the distribution network. However, this is outside the scope of this book.

The microbiological and biochemical changes are greatly reduced by storing products at low temperatures. Effective temperature control is, therefore, a critical factor in preventing the development of spoilage organisms and ensuring that dairy desserts achieve their potential shelf life, as well as minimising any food poisoning risk.

The Food Hygiene (Amendment) Regulations 1990, as amended by the Food Hygiene (Amendment) Regulations 1991, formalised this requirement for the industry, by including dairy desserts with a pH >4.5 in the list of foods which must be stored and distributed at temperatures of less than 8°C. However, the regulations failed to include any temperature requirements for desserts with a pH of 4.5 or below, and therefore, many yogurts and fromage frais products escape this mandatory requirement. It