11.8.1 Shelf life of new products

In general a shelf life can be assigned to a new product by analogy with an existing product, using the knowledge of the development confectioner and packaging technologist to choose the most appropriate reference.

Nevertheless it is essential to confirm this judgement by checking the performance of a new, or altered, product under a variety of conditions as well as normal storage.

11.8.1.1 Testing products for shelf life. A suitable range of conditioned cabinets should be available, for example:

Ambient 20°C 65% RH
Ambient 25°C 80% RH
Ambient 32°C 60% RH
Ambient 32°C 80% RH

Local circumstances may make other conditions more appropriate, e.g. the cold dry conditions of a Canadian winter, or cycling of temperature and humidity to promote the development of bloom to be expected under unregulated storage and thus the development of means to retard it.

11.8.1.2 Procedures. Samples should be kept in these cabinets together with a standard reference product of a similar nature, either an 'own company' product or a competitor's product which is known to have a satisfactory shelf life and performance in the appropriate market and whose age can be established. Consideration should be given to the nature of the product and package and a decision taken as to whether additional tests, e.g. for light fastness, cold storage or cyclical temperature or humidity changes are desirable and if they are, arrangements should be made to incorporate them into the test schedule.

Initially keeping tests are only intended to compare the keeping properties of a new or amended product with those of a standard product. With this in mind, it should be possible for product knowledgeable personnel to use their judgement and give a reasonably accurate shelf life based solely on an accelerated keeping test, confirmed by a long-term keeping test and long-term storage trial.

It is essential that all assessments of keeping tests should be made by expert staff. The standard product and its known response to test conditions will indicate to the expert any cabinet unreliability. Such a guide as to the reliability of storage conditions is particularly important when a new product is on test. A minimum of three assessors is required at the time of tasting.

New products may require a 'fresh' sample for comparison at the time of tasting and this would be obtained by remaking.

11.8.2 Types of test

11.8.2.1 Accelerating keeping test. This test should last 6–8 weeks with the samples being examined weekly. The accelerated deterioration is caused by elevated temperature and increased humidity. A revised product deteriorating more than standard on this test should not usually proceed to production. Where a revised/new product keeps better than, or as well as the standard it is assumed that it will have an equivalent shelf life. This, however, must be confirmed by a long-term test.

11.8.2.2 Long-term keeping test. This test would last up to 18 months and take place under ambient conditions (20°C and 60% RH) with 4-weekly examinations. Standards would again be used and this test should confirm the accelerated keeping test with which it initially runs concurrently. The range of keeping cabinets listed previously can be used for long-term testing to give a more detailed profile of the product's keeping characteristics.

11.8.2.3 Long-term storage test. This test would use production-made samples of the revised/new product, and would eventually supersede the long-term keeping test in confirming its shelf life.

11.8.3 Results of keeping test – scoring system

Chocolate products should be scored by the five characteristics or attributes listed below, although (4) and (5) will not always be needed.

1. appearance
2. flavour/taste
3. texture
4. colour
5. others (specified, e.g. odour)

11.8.3.1 Determining the attribute score. Only the test product is scored, and the score depends on its comparison with the standard as shown in Table 11.2.

11.8.3.2 Overall product score. The product should also be given an overall product score (1–5) based on the agreed attributes and the above criteria. One attribute having a reject score means that the whole product must have a reject score. Using the keeping test scoring forms, each assessor (minimum of three) should independently taste the test and standard products, individually score the attributes and overall score and make appropriate comments on a keeping test form (Figure 11.1).

Table 11.2 Determining the attribute score in a keeping test

Test product score	Result	Score criteria
5	Acceptable	The test product has kept better than the standard product
4	Acceptable	The test and standard products are of equal quality. They have deteriorated at the same rate
3	Reassessment is an option	Test product is slightly inferior to standard but nothing undesirable has developed
2	Reject	Test product is inferior to standard, but further work may be recommended
1	Reject	Test product is much inferior to standard and further work is not recommended

The person coordinating the keeping test should then collate the results and, in conjunction with the assessors, come to an agreed result. This agreed result, including comments, should be entered on a keeping test summary form (Figure 11.2), after each tasting session.

The test ends either at a pre-arranged time or when the product is judged to have reached the end of its acceptable shelf life.

PRODUCT: PRODUCT REFERENCE(S): REASONS FOR TEST: ADDITIONAL SAMPLE NOTES:			DATE OF TASTING	SAMPLE AGE WEEK/MONTHS: CABINET DESCRIPTION: TEMPERATURE: HUMIDITY:
ATTRIBUTE	COMMENTS		TEST SCORE	NOTES
	STD PRODUCT	TEST PRODUCT		
APPEARANCE				
FLAVOUR/TASTE				
TEXTURE				
COLOUR (IF APPLICABLE)				
OTHER (SPECIFY)				
TOTAL PRODUCT				
RECOMMENDATION/ACTION AT THIS SAMPLING 1. Continue test as trial product: satisfactory: Y/N 2. Comments:		FINAL RECOMMENDATION - TEST COMPLETE	SCORE GUIDE 5. Better than standard 4. Same as standard 3. Slight difference, nothing undesirable 2. Inferior to standard 1. Much inferior	

Figure 11.1 A keeping test form.

Date of Tasting	Age of Sample Weeks/Months (Delete as Necessary)	CABINET																											
		Description						Description						Description						Description						Description					
					°C		% RH				°C		% RH				°C		% RH				°C		% RH				°C		% RH
		Attributes - Score																											
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

Figure 11.2 A keeping test summary form.

11.9 Packaging materials – taint testing

As mentioned earlier, packaging materials can be a source of contamination leading to the early deterioration of chocolate. Milk chocolate in particular is very susceptible to taint resulting from inadequately controlled packaging.

Modern methods of printing and the use of, for example, water or alcohol based inks, together with a heightened awareness of the need for very strict quality control at all stages of the production and packaging of chocolate products has greatly reduced the likelihood of taint from packaging.

Nevertheless incoming packaging materials should be regularly checked and three principal methods of testing are available.

11.9.1 Robinson test

This test is widely used throughout Europe. A piece of the test material, 20 cm × 22 cm, folded and perforated, not in contact with the product, is kept in a jar with 15 g of grated fresh milk chocolate, in the dark, for 48 hours at 20°C and 75% RH. A control is set up either without the material being tested or, if the material is printed, with an unprinted version of the material.

The evaluation of the test is carried out by a panel of assessors who compare blind the chocolate from the test with that from the control. The

intensity of any off-flavour is evaluated on a numerical scale as follows (scored by half points):

0 No difference in flavour
1 Just perceptible difference in flavour
2 Just definable off-flavour
3 Definite off-flavour
4 Strong off-flavour

The scores given by the assessors are added and the total divided by the number of assessors: e.g. eight assessors with scores of 2.5, 3.0, 2.0, 1.5, 2.0, 2.5, 1.5, 3.0 giving a total of 18; dividing the total by 8 gives 2.25 which on rounding up to the nearest 0.5 becomes 2.5. Acceptance levels are generally taken as 1.5 for unprinted material and 2.5 for printed.

11.9.2 Gas liquid chromatography (GLC)

By this method levels of residual solvents in printed materials can be monitored against agreed standards such as a global maximum of 20 mg/m^2 with a sub-total of hydrocarbons not to exceed 10 mg/m^2.

11.9.3 Aroma index

This method uses a Buchi Vapodest 100 or similar steam distiller to determine the presence and level of taint in packaging materials. Filtered condensate from the distiller is measured in a spectrophotometer at 280 nm and the absorbance multiplied by 100 to give the aroma index.

Packaging for chocolate products should be rejected if it has an aroma index higher than 35.

11.9.4 General

It should be mentioned that there are occasions when analytical instruments fail to pick up taints which are readily detected by a well trained human nose or palate. For this reason the availability of a Robinson type test with experienced assessors is an essential backup to any form of scientific taint testing of packaged materials.

While it must be the responsibility of the material supplier to ensure that his product meets the agreed scientifically quantified criteria of GLC and/or aroma index testing, it is ultimately the chocolate manufacturer who must ensure that the consumer receives a product free from any contamination from the packaging designed to protect it.

Not all confectionery manufacturers can equip themselves to carry out all the appropriate scientific tests for taint, although all suppliers should,

yet all must ensure that they have the trained staff for organoleptic checking of the materials which they use. Indeed the same staff could well be those who carry out the analysis of keeping tests.

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12 Ready-to-eat breakfast cereals

J.A.K. HOWARTH

12.1 Introduction

Ready-to-eat breakfast cereals belong to the category of foods that are inherently stable and have a long shelf life. Thus, the requirements for determining shelf life are quite different from products which have a short shelf life, for example, chilled foods which may only be stable for three to four days. The factors affecting the shelf life are also quite different; deterioration during life will probably not affect the safety of a breakfast cereal but will have an impact on consumer satisfaction.

Ready-to-eat breakfast cereals are designed to be eaten straight from the packet, requiring no preparation, and so do not include breakfast items such as porridge. It is therefore important for the manufacturer to identify the parameters most critical to consumer satisfaction and ensure that these are the characteristics preserved throughout the life of the product. This chapter gives a broad outline of the means of determining cereal shelf lives and includes some pointers and general guidelines for methodology which could also be applied to other 'long life' products.

If determination of shelf life is new within an organisation then one of the first steps is to ensure that the senior management fully understands the implications of the work. There must be clear standards laid down as to what denotes acceptable quality at the end of shelf life and everyone must be aware of these and accept them. Failure to do this at an early stage could lead to difficulties when trying to implement any new standards.

There are two main areas of interest when looking at stability of breakfast cereals – organoleptic properties and analytical values. Appearance, flavour and texture of the product are important, as are analytical values such as vitamin/mineral content where the product has been fortified and a claim made. These areas are legally binding and it is important to have evidence to back any claims made regarding stability and analytical data (IFST, 1993).

Although it is not necessary with products like cereals to put a date of manufacture on the product (although a 'lot' code is required), there is a 'Best Before' date and consumers now expect there to be a fairly long time remaining after they have purchased the product before it becomes unacceptable. In particular, major retailers are now demanding that 75%

of the shelf life is still available when the product is delivered to their depots.

Shelf life testing and date-marking of the product can only give information on the stability of a full, sealed package – it cannot give information relating to the consumer who keeps an open carton in the cupboard for six months (IFST, 1993). Laboratory testing can give an indication of what could be expected but cannot be solely relied upon in setting the shelf life.

The manufacturer cannot be expected to guarantee a shelf life once the pack is opened, and when the product has been abused in some way.

12.2 The products

The product group of 'breakfast cereals' contains a wide range of products as can be seen on the supermarket shelves. These products can have quite different characteristics, while all being expected to have a similar shelf life.

The products can be separated into five groups which may need slightly different treatments.

12.2.1 Uncoated cereals

Examples of these are flakes, crisp rice, shredded bran. These products are typically low in moisture content – usually below 4% – and are inherently stable if not exposed to the environment. These would traditionally be expected to have a long shelf life with very little change in product characteristics.

12.2.2 Coated products

Examples of coated products are sugar coated flakes, honey nut flakes, coated extruded products. These products still have a relatively low moisture content, usually below 5%. They tend to be more hygroscopic than uncoated products and depending on the type of coating, a potentially unstable ingredient may be present. For example, a cereal with a nut based coating can suffer from rancidity problems if not handled in the correct way.

12.2.3 Products with added components

Examples are flakes with raisins, flakes with mixed fruit. The moisture content of the whole cereal may be around 7%; however this could be made up of cereal at 3% and fruit at 12%; these are products which will

show very different storage characteristics. Moisture transfer between cereal and fruit can be the critical factor in determining shelf life rather than the ingress of moisture from the environment. A product with a higher moisture content will generally be less stable than the one with a lower moisture content (Labuza, 1982).

12.2.4 Muesli products

These products have a fairly high moisture content, so moisture pick-up from the environment is not as critical as the stability of the ingredients themselves. A muesli product can only be acceptable for the time its least stable ingredient remains acceptable.

12.2.5 New products

These can take any form, or could be a combination of any of the particular cereal types mentioned above. If the product is a new combination then the shelf life must be determined, although previously gained experience can be used to give some guidance.

As discussed above, moisture content plays an important role in determining the shelf life of breakfast cereals. Since most products do not usually support microbial activity, microbial spoilage of the food is not a critical factor. Changes in moisture content can affect the organoleptic properties and this is the main criterion to be used.

Most cereals will reach an equilibrium moisture content naturally, which will remain stable for many years if stored in a relatively constant environment. Examples of this have been cereals which were discovered after 40 years and showed no signs of spoilage. The moisture content is usually higher than would be acceptable organoleptically. This only serves to emphasise the importance of organoleptic characteristics in storage testing.

12.3 Factors affecting shelf life

There are a number of factors which will affect the shelf life of a breakfast cereal and these will have differing degrees of influence. All must be taken into consideration and as with most foods, the better the control in all the areas, the greater the confidence in achieving the shelf life required. The main factors which affect shelf life have been identified as:

- raw materials
- processing

- packaging materials
- climate and storage conditions.

The first three are within the control of the manufacturer and although the fourth cannot be controlled, the effects can be predicted to some degree.

12.3.1 Raw materials

The majority of raw materials used to manufacture breakfast cereals are to be processed in some way – the main exceptions to this being fruit/nut additions to products and muesli type products. As mentioned earlier in this chapter, microbial spoilage of breakfast cereals is very rare and the use of Hazard Analysis Critical Control Point (HACCP) technique can ensure that major hazards are either eliminated or controlled.

The main factor therefore concerning raw materials is that of consistently high quality and each material must have the critical factors identified which will allow manufacture of a high quality product.

Materials which may cause some concern microbiologically are ingredients such as milk powder, cocoa powder, dried fruits, nuts – particularly coconut, and any which do not undergo a sufficiently high temperature processing. The specifications for these materials should lay down stringent standards and the quality system must ensure that these requirements are met before the materials are used.

Potential causes of rancidity in a product can originate from nuts, and their quality must be carefully controlled to ensure that these materials do survive the long shelf life in an acceptable state.

Moisture content and equilibrium relative humidity (ERH) of fruit are critical, and depending on the quantity of fruit added to the cereal, they will affect the overall acceptability of the product.

High-quality consistent raw materials will ensure that the required shelf life will be met.

12.3.2 Processing

As with most foods, heat treatment extends the life of the materials and also ensures a minimum of microbial contamination.

Most breakfast cereals, after processing, have virtually no microbial count, but a low moisture content and an ERH which will not support any microbial growth.

Although breakfast cereals are processed, the conditions of processing are not as severe as those in the canning industry for example. Cereals are manufactured to an image, the main criteria for acceptance being organoleptic properties, moisture content and bulk density. That image will also have an acceptable range within which variation is acceptable. And so,

whilst processing does have a definite influence on the shelf life, its main function is to convert the raw materials into highly palatable food products, with the production of certain distinct characteristics in the foods, such as attractive colour, pleasant flavour and crunchy texture.

12.3.3 Packaging materials

Packaging used for breakfast cereals serves two purposes – protection from spoilage and protection from physical damage. The most common form of packaging in use is that of a paperboard carton with an inner liner containing the food. The inner liner will provide most of the protection to the food while the outer carton provides protection from physical damage and also from potential tampering.

The main purpose of the inner liner is to protect from moisture transfer so as to preserve the product characteristics. The most effective type of liner will be determined during shelf life testing. A liner which has barrier properties which are too effective can give other problems in storage, for example, the generation of unpleasant odours in the headspace. This is therefore a major consideration. Antioxidants can increase the expected shelf life and in some countries can be used in the liner material for this purpose (Labuza, 1982). As will be discussed later, compromises may have to be made on some occasions to allow for these factors.

12.3.4 Climate and storage conditions

As previously discussed, the liner type is crucial to preserving the shelf life of the product and the external conditions can have a considerable effect on the product. During determination of shelf life the climate of the market must be taken into account; for example, the requirements of products stored in Mediterranean/tropical climates are quite different from those destined for Northern Europe.

The destination country of the product is also of importance as transport facilities and hence the potential for picking up taints during transport and storage must be considered and, if possible, minimised. If there are poor standards of warehousing then the risk of infestation may be high. This knowledge may mean that a shorter shelf life is appropriate for some markets.

All the factors which may contribute to the length of acceptable shelf life in the product cannot be listed here. However, an attempt has been made to highlight the major areas. The most important factors will depend on the specific product and market, and the areas considered above will assist in identifying the most critical ones for that particular product. Methodology and useful checklists are available in other texts (IFST, 1993).

12.4 Determination of shelf life

The initial determination of shelf life may have been carried out on a development product which will have given an indication of the expected shelf life. A product which remains on the market for a long period of time may need to have its shelf life re-evaluated periodically as changes are made to raw materials, processing, or packaging materials. This emphasises that once the life has been determined, this is not the end of the story – monitoring on a regular basis must continue to ensure confidence in the product. The methodology for determination and monitoring of shelf life of breakfast cereals can be divided into a number of areas all of which are important:

1. Initial determination of shelf life:
   (a) identification of critical product characteristics;
   (b) break point analysis (critical moisture content determination).
2. Shelf life testing:
   (a) samples;
   (b) storage conditions;
   (c) assessment of results.
3 Monitoring activities:
   (a) new markets;
   (b) packaging materials changes;
   (c) processing/raw material changes.

12.4.1 Initial determination of shelf life

Before beginning a shelf life test there are some basic pieces of information which must be sought. These will set the ground rules for a particular product and will ensure that the correct test is set up to provide useful data.

12.4.1.1 Identification of critical product characteristics. When planning a test to determine or confirm the shelf life of a product, it is important to ensure that the most critical factors have been identified.

With breakfast cereals, each product can be quite different and the characteristics which are important for the acceptability of the product are those which must be tested.

Selection of the factors will also depend on whether the test is an initial determination or a confirmatory test when a fair amount of information about the product has been obtained.

For all breakfast cereals sensory attributes are most important as it is unlikely that any harmful substances will be generated during processing and storage. If this is to be the main guide, then the selection of assessors for sensory evaluation is critical. Details about this can be found in many

relevant texts (Amerine *et al.*, 1965). One of the most important flavours/off-flavours is that of rancidity and it is well known that some people are more sensitive to it than others and the use of trained assessors may be useful.

Analytical data can also be used to evaluate changes occurring in the product and appropriate parameters should be selected – the most common of these being:

- moisture
- vitamins
- rancidity measures

If there is no on-site laboratory, a reputable laboratory may be used. The same laboratory should be used throughout the testing period to maintain consistency.

Analytical tests together with sensory evaluation can give an accurate determination of shelf life, and it is important that both these are used (Birch *et al.*, 1977).

12.4.1.2 Break point testing. The purpose of break point testing is to determine the moisture level at which a product is no longer acceptable.

Samples of different moisture levels are prepared and presented to selected assessors in a random order. The samples can be prepared in a laboratory or by selecting suitable samples from production runs. The target moisture levels should be determined and samples close to these selected. The amount of water to be added to the product is calculated and weighed into trays. These trays are placed in a plexiglass chamber with the required quantity of product. The chamber should be sealed and allowed to stand until all the water has been absorbed – usually 4–7 days. Once the water has been absorbed the product should be allowed to equilibrate for one week in glass jars. After checking of moisture content the samples can be submitted to the sensory panel. The assessors rate the samples organoleptically and the moisture level at which the product is not acceptable is determined. This procedure should be agreed by a number of senior personnel within the organisation as this will form the basis for determining the acceptable shelf life of all products.

Different products will have different break points depending on their composition and end use.

12.4.2 Shelf life testing

The specific methodology used for a shelf life test will depend on the type of product and the resources available. However, there are some general rules which will help to ensure that the data collected provide a realistic assessment of product shelf life.

12.4.2.1 Samples. The specific arrangements for sensory testing will depend on the available resources, but in general, a minimum of six experienced assessors is needed to give a meaningful result.

Accelerated tests require at least 18 cartons of cereal packaged in the same packaging as intended for storage. It is not usually necessary for each assessor to have a full carton, a bowl for each will be sufficient.

Ambient testing will also need at least 18 cartons of cereal which should be stored under typical conditions, e.g. in a distribution warehouse.

If enough food is envisaged to be left over after sensory evaluation for the analytical work, then one carton per assessor is sufficient. Otherwise a second carton may be needed for the analysis.

Results plotted graphically are more easily interpreted and trend lines can be drawn.

The shelf life determination should extend beyond the proposed life of the product as this will give extra information concerning what may happen once the product is in the home of the consumer.

During testing, a reference sample available to compare with the sample under test is desirable. However, no acceptable method of preserving a cereal for this purpose is known (Stone *et al.*, 1985). A freshly made sample will provide some reference, and the use of an experienced panel should be adequate.

12.4.2.2 Storage conditions. Storage under a number of different environmental conditions (including the use of accelerated storage) can give some predictive results.

In general, there are three types of testing conditions that can be used which have different purposes (see Table 12.1).

The most suitable conditions should be selected depending upon the product and the time available before shelf life must be established. For example, in the development of a new product it may not be possible to complete an 18 month ambient test; an accelerated test could be used to give an initial prediction, followed by a full test afterwards.

Table 12.1 Types of storage conditions and their uses

Test	Suitable for	Not suitable	Time
Ambient	All products	–	18 months
Accelerated 38°C	Flaked/puffed products	Fruit products, coated	18 weeks
Tropical 38°C 90% humidity	Investigating packaging	General shelf life prediction	Variable

Table 12.2 Appearance scores for a product stored under ambient conditions

Month	Appearance
0	7.2
1	6.2
2	5.8
3	6.5
4	5.3
6	6.2
7	6.2
8	5.8
9	5.7
10	5.7
11	5.7
12	7.3
13	6.0
14	6.0
15	6.2
16	6.0
17	7.5
18	6.3

12.4.2.3 Assessment of results. Data collected during a shelf life test will consist of sensory as well as analytical data. Analysing the data and looking at the correlation coefficient, percentage fit and slope to assess for trends from the sensory scores and analysis results will give an effective prediction. The correlation coefficient between, for example, sensory scores and analytical results gives a good indication of whether or not there has been significant quality deterioration over time. In general, it is accepted that the higher the correlation coefficient, the more significant the observed change.

In the example shown in Table 12.2, there is little change in the appearance scores against time reflected in a slope of 0.01, a correlation coefficient of 0.12 and a percentage fit of 1.5.

Results plotted graphically are more easily interpreted and trend lines can be drawn as in Figure 12.1 (the higher the score, the higher the acceptability).

Using the results from the break point analysis, it can be determined when the product becomes unacceptable.

For analytical data, the critical point may be when a vitamin falls below the intended nutritional claim.

Addition of some vitamins, in particular vitamin C, can give some stability problems and this is affected by the method of application and storage conditions (Labuza, 1982).

Figure 12.2 shows little loss of vitamin C when applied to the product, in this case, separately from other vitamins.

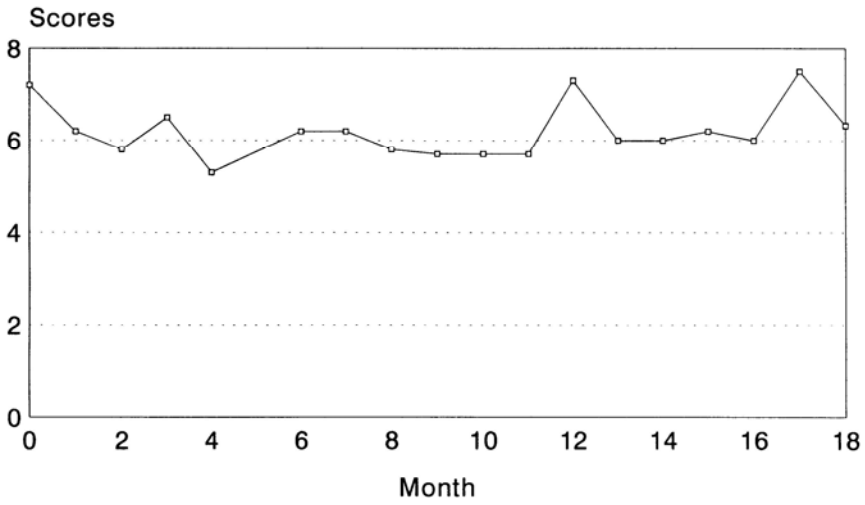


Figure 12.1 Appearance scores plotted to show trends more clearly.

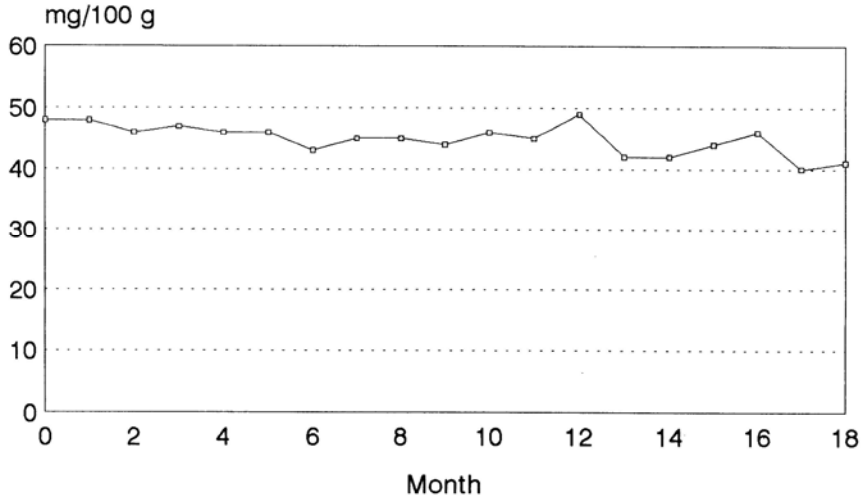


Figure 12.2 Vitamin C added as a separate spray showing little change on storage.

This, however, changes when vitamin C is added together with other vitamins. While the vitamins are stable in solution, once on the product some changes are observed (see Figure 12.3). The graph shows a rapid initial loss and this could also result in development of off-flavours and odours.

In general, one result showing a marked adverse trend would not

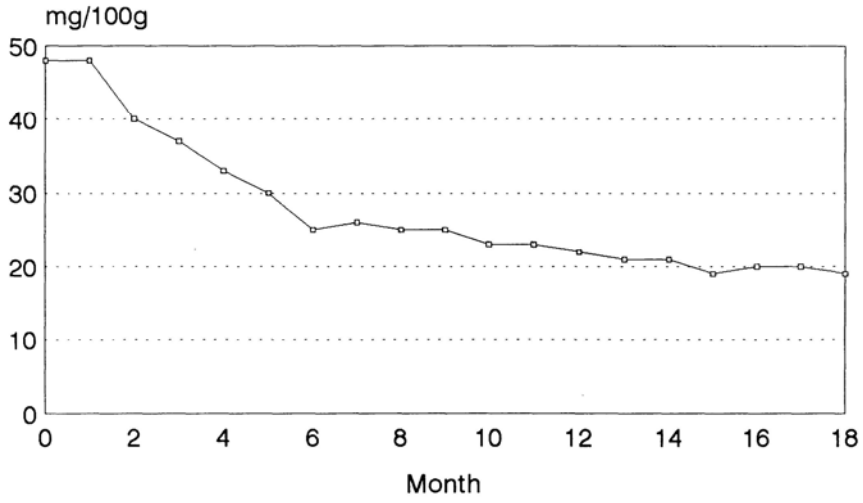


Figure 12.3 Vitamin C added as one spray with other vitamins, showing changes of vitamin C with storage.

indicate a definite cause for concern, as this could be a one-off sample with a fault in the packaging. Two consecutive results which show marked vitamin degradation would however need investigation.

The following examples illustrate the methodology of testing and how the shelf life can be determined.

12.4.3 Example 1 – flaked/puffed product

The steps involved in testing this type of product, assuming it is a new product are:

1. identification of critical attributes;
2. break point analysis;
3. test conditions;
4. interpretation of results.

12.4.3.1 Critical attributes. As the product does not have any 'high risk' ingredients, there are no specific factors which may need specialist assessors.

The most critical factors for this type of product are:

- appearance
- flavour/off-flavour
- texture (crisp/crunchy)

- moisture
- vitamins/minerals if fortified

12.4.3.2 Break point analysis. This identifies the moisture content at which the product quality becomes unacceptable from a sensory point of view. It is assumed that for this product the break point moisture level is 6%. This will be used to confirm the final shelf life.

12.4.3.3 Test conditions. In the initial determination of shelf life, both accelerated and ambient testings are useful if run parallel to one another.

The accelerated test will give a prediction of the full shelf life and may highlight any early problems.

12.4.3.4 Interpretation of results. Figures 12.4 and 12.5 show data from storage of a product under ambient conditions. The test ran for 18 months and Figure 12.4 demonstrates that the product reached its break point in 16 months. This would suggest that the product should not have a shelf life longer than 16 months.

Figure 12.5 confirms the product acceptability by sensory evaluation. For example the data for texture yield:

Intercept	8.25
Slope	− 0.09
Correlation coefficient	0.72

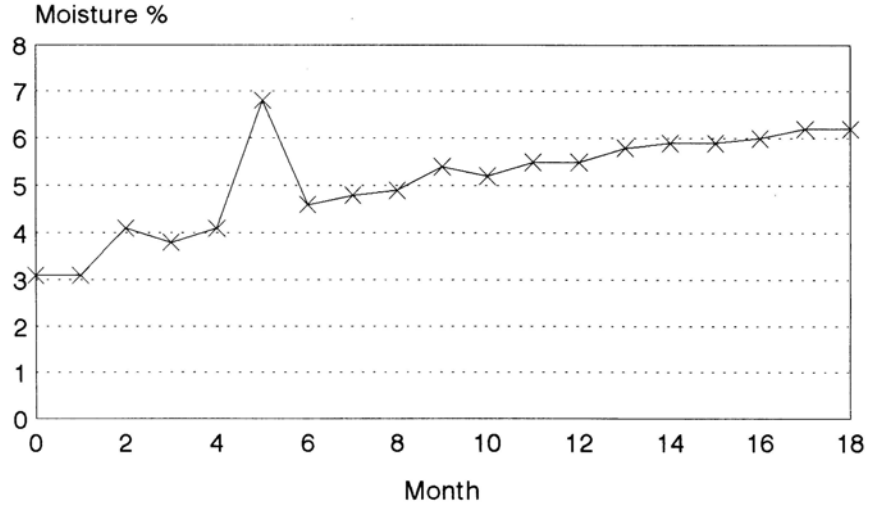


Figure 12.4 Moisture content of a product stored in ambient conditions.

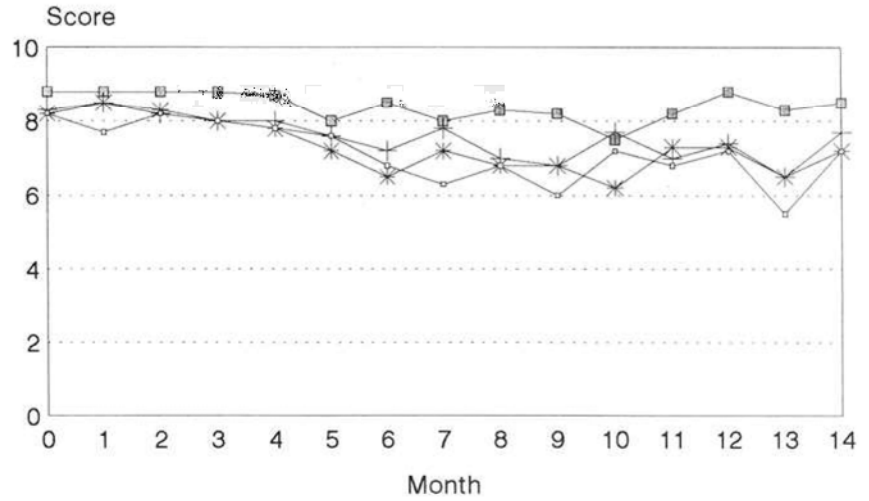


Figure 12.5 Sensory scores of a product stored in ambient conditions. □, Appearance; +, texture; *, flavour; ■, off flavour.

It may be concluded that there were no real trends in the reduction of acceptability.

The same product tested under accelerated conditions showed little deterioration in product quality (Figure 12.6) and little increase in moisture (Figure 12.7).

From these results the predicted shelf life from accelerated testing would be 18 months (based on one week accelerated life being equivalent to one month ambient life). However, with the ambient results the acceptable recommendation would be 16 months.

The results of the test can only be used to predict the expected shelf life when using the same product formulation, manufacturing process and packaging materials. Any major changes will invalidate the prediction based on accelerated test alone.

Break point testing/tropical conditions can be used to assess different packaging materials without doing a full test.

12.4.4 Example 2 – Cereal with added components

Combining two or more materials together which have very different storage properties can give rise to complex shelf life problems. All constituent parts must be acceptable at the end of the shelf life and the percentage combination can have a marked effect. A good example is flakes with raisins.

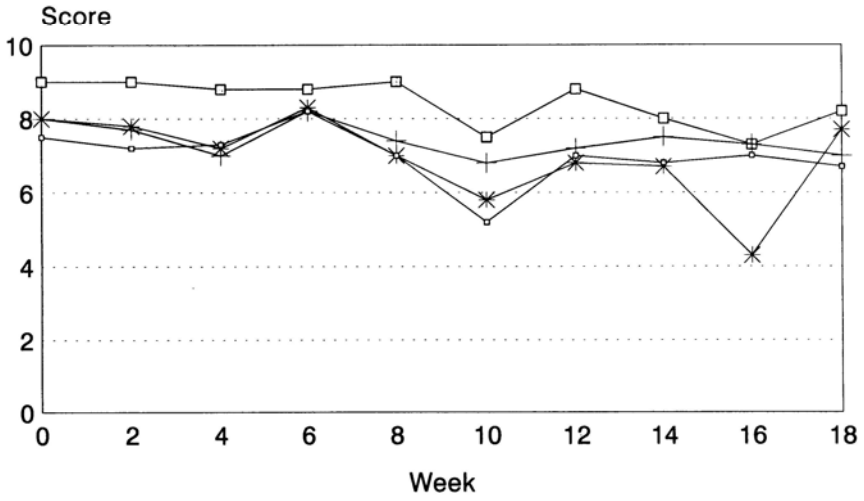


Figure 12.6 Sensory scores of a product stored under accelerated conditions. □, Appearance; +, texture; *, flavour, ■, off flavour.

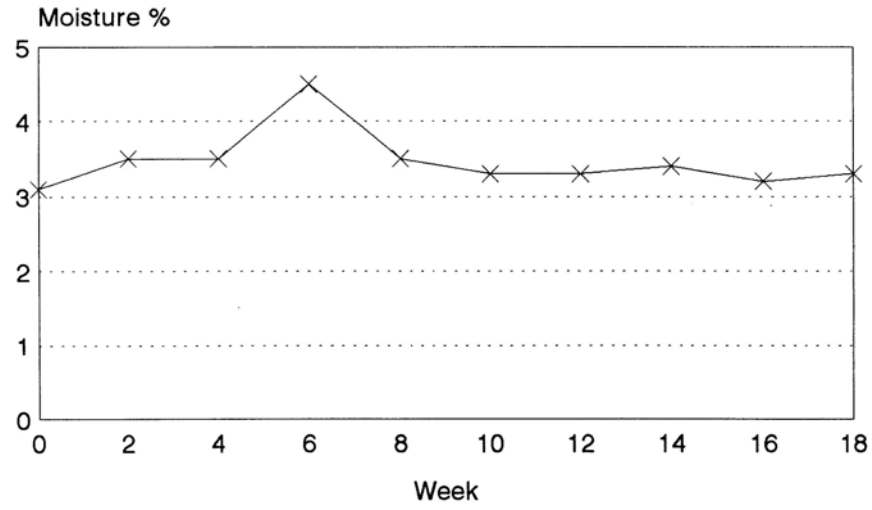


Figure 121.7 Moisture content of a product stored under accelerated conditions.

12.4.4.1 Identification of critical attributes. The following are identified as critical attributes:

- Appearance – plump, glossy fruit, 'bright' flakes.
- Texture – crisp flake/soft fruit.
- Flavour – fresh, fruity flavour, fresh bran flavour.
- Analytical parameters will include:
  - moisture of flakes and fruit
  - vitamins/minerals.

12.4.4.2 Break point analysis. Taking a homogeneous product, the overall moisture can be determined when the product is no longer acceptable. However, in this case, the 'total' moisture is not the critical parameter, but the values for the individual parts of the product are.

The break point for this type of product would have a maximum and minimum value, for example, a minimum of 2.0%, a maximum of 8.0% with a maximum for cereal at 7.0%.

12.4.4.3 Test conditions. Only ambient test conditions are suitable for products with fruit added. Accelerated tests, i.e. at high temperature, will cause premature hardening of the fruit and will not give an accurate prediction. Accelerated tests may be used to look at the stability of nutrients but not organoleptic properties.

For sensory assessment, information should be obtained separately for fruit and flake texture.

12.4.4.4 Interpretation of results. In Table 12.3 it can be seen that there is little change in the organoleptic properties of the product. However, there are clear trends in the moisture contents of the flakes and fruit. The previously determined break point of the product would, from these figures, suggest an acceptable shelf life of about 14 months, based on moisture content. The organoleptic properties confirm this. However, with this type of product experience has shown that organoleptic properties are more critical.

Another example (Table 12.4) shows a marked deterioration in fruit texture and for this product a shelf life of only 8 months would be acceptable.

In this situation, a decision then has to be made as to whether to modify the product or packaging or offer a reduced shelf life. Any changes to the product/pack should require re-testing.

Table 12.5 shows the effects of different levels of fruit addition. The higher level affects flake quality whilst the lower level results in deterioration of the fruit.

With other materials, e.g. nuts, it is likely that oxidative change rather

Table 12.3 Data from the shelf life test of a product over 13 months showing organoleptic properties and moisture content

Month	Appearance	Texture fruit	Texture flake	Flavour	Off flavour	Moisture flake	Moisture fruit
0	7.5	7.25	6.5	7.5	8.5	4.1	11.4
1	7.5	7.33	6.33	7.17	8.6	4.1	9.3
2	7.17	7.17	6.0	7.17	9.0	4.3	8.7
3	8.17	6.5	5.67	7.17	8.3	4.6	8.3
4	7.8	6.2	6.8	7.6	9.0	5.0	8.8
5	7.33	6.67	6.5	7.5	8.6	5.0	8.1
6	7.67	7.17	6.17	7.5	8.1	5.4	8.8
7	7.83	5.67	6.33	7.17	8.1	6.7	8.5
8	7.4	6.2	6.0	7.4	9.0	6.6	8.1
9	7.6	5.6	5.6	7.2	9.0	6.5	7.0
10	7.4	6.2	6.0	7.4	9.0	6.6	7.9
11	7.6	6.6	6.2	7.0	8.6	6.9	8.2
12	8.0	6.5	6.0	6.5	8.3	7.2	8.4
13	7.5	6.17	5.33	6.17	7.5	7.2	8.2

Table 12.4 Texture scores for a product stored under ambient conditions

Month	Texture of fruit
0	7.3
1	7.3
2	7.2
3	6.5
4	6.2
5	6.2
6	6.2
7	6.0
8	5.7
9	5.3
10	5.3
11	5.3
12	5.0
13	4.8

than moisture transfer will be critical. In this case, either the quality of the nuts or oxygen availability, or both will be the life controlling factor.

12.4.5 Example 3 – Coated products, e.g. extruded, coated cereal

This type of product can consist of any kind of 'base' material, e.g. corn, oats, wheat, rice, and can have various coatings, from a simple sugar coating to one consisting of honey, nuts, cocoa powder and so on.

Table 12.5 Effects of different levels of fruit addition on fruit and flake texture

Month	15% fruit Flake texture	15% fruit Fruit texture	25% fruit Flake texture	25% fruit Fruit texture	40% fruit Flake texture	40% fruit Fruit texture
0	7.5	7.7	7.2	7.2	7.9	7.7
1	7.7	7.6	7.7	7.2	7.7	7.5
2	7.8	7.3	7.3	7.5	7.5	7.5
3	7.6	7.4	7.3	7.0	7.5	7.6
4	7.5	7.4	7.6	7.2	7.2	7.6
5	7.6	7.0	7.5	7.3	7.0	7.4
6	7.7	7.0	7.4	7.2	6.8	7.4
7	7.8	6.8	7.2	7.7	6.4	7.5
8	7.3	6.8	6.8	7.3	6.4	7.3
9	7.5	6.7	7.5	7.2	6.2	7.6
10	7.7	6.4	7.4	7.2	6.1	7.7
11	7.3	6.2	7.0	6.5	6.0	7.5
12	7.6	6.0	6.7	7.3	5.6	7.5

12.4.5.1 Identification of critical attributes. An oat based product with a honey and nut coating is taken as an example.

The most critical attributes will include:

- Appearance: dullness/glossiness
- Flavour: rancidity and other potential off-flavours; loss of honey/nut flavour
- Texture: stickiness, softness
- Analytical parameters: moisture
  PV (peroxide value)
  FFA (free fatty acid)
  vitamins/minerals

12.4.5.2 Break point analysis. As an increase in moisture content can cause changes other than softness, the break point for this type of product is usually lower than for other cereals. For this example a maximum moisture content of 5.0% is assumed to be the critical value.

12.4.5.3 Test conditions. Ambient conditions are most suitable; accelerated tests (high temperature) may cause some unusual effects, e.g. increased stickiness, which would not be seen in ambient conditions.

12.4.5.4 Interpretation of results. Figures 12.8 and 12.9 show clear trends in increase in moisture content and reduction of texture quality. Using the break point analysis moisture level, the product would no longer be acceptable after 8 months. The decision must then be made as to whether this life is acceptable. If the alternative is to reformulate then the product must have a full storage test before the shelf life can be confirmed.

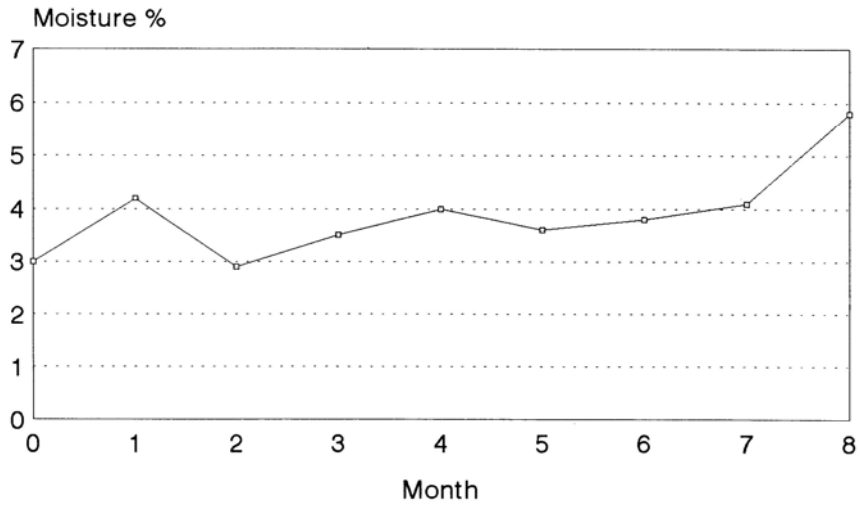


Figure 12.8 Moisture content during storage. Break point level 5%.

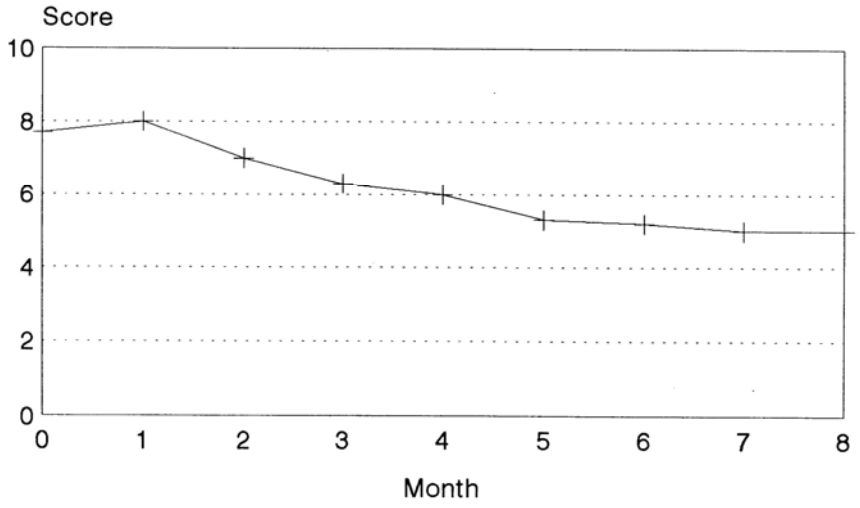


Figure 12.9 Texture scores during storage. Break point level 5%.

Figure 12.10 shows a clear trend in FFA and PV results which would suggest potential rancidity and off-flavour development.

However, in this case there has been no deterioration in the assessors' rating of flavour (Figure 12.11) which suggests that the increases in PV

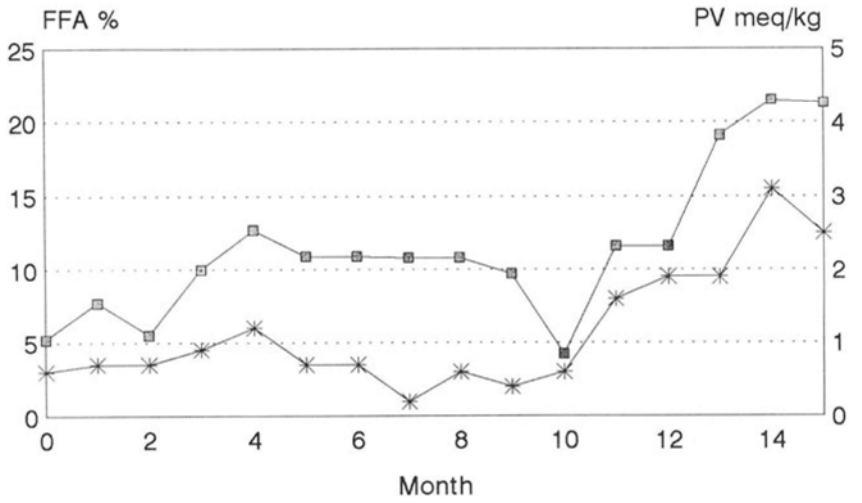


Figure 12.10 PV and FFA levels during storage. *, FFA; ■, PV.

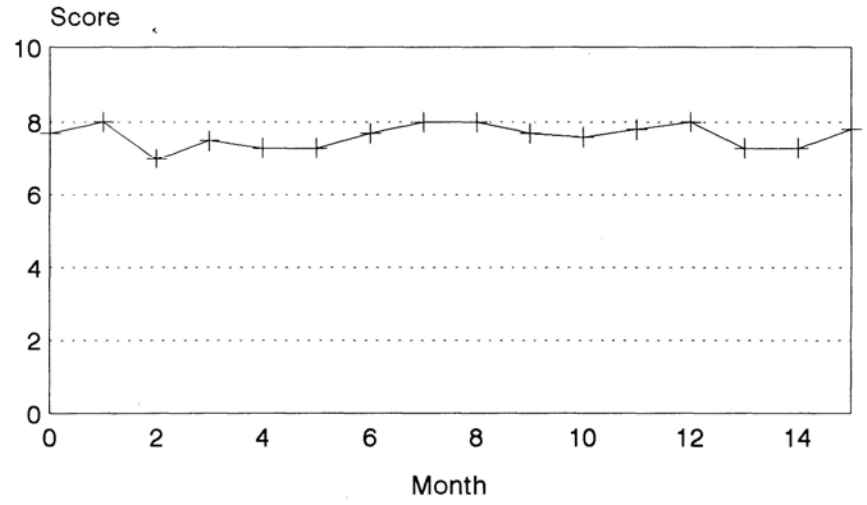


Figure 12.11 Flavour scores during storage.

and FFA are not reflected in the acceptability of the product. This again emphasises that both sensory and analytical data should be used together as they provide complementary information.

12.4.6 Monitoring activities

Once the shelf life has been initially determined, it should be monitored on a regular basis to take into consideration changes in raw material/processing which might not be major changes, but could over a period of time cause a drift in product quality.

The frequency of re-testing will depend on the facilities available and the complexity of the product. For example a product containing 'high-risk' ingredients may need to be re-tested every 2–3 years whereas a relatively stable product may only need to be re-tested every 5 years.

A programme should be set up to ensure all products are re-examined on a regular basis. This will also give some confidence against the risks in shelf life testing of looking at a typical situation rather than the worst case (Paine, 1992). Mathematical models can be used to predict shelf life from currently available data which can help to minimise repeat testing (Labuza, 1982).

If there are any changes to raw material or, more critically to packaging materials, then a full test should be carried out before the change is confirmed. This will minimise the risks involved.

12.5 Conclusions

In this chapter the main criteria for consideration when evaluating the shelf life of breakfast cereals have been discussed. As indicated, there are some points for general consideration which relate to all types of cereals. However the wide diversity of cereal products means that each product should be treated on an individual basis. Lessons learned from other products can be used, but this information should not be treated as absolute. Small changes in processing or raw materials can have a serious effect on storage life.

Each product category and individual company facilities must determine the exact nature of the testing carried out, and the examples quoted should give an indication of how the data collected can be analysed and interpreted to provide useful storage information. It is important to design the programme to suit individual requirements.

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13 The storage of thermally processed foods in containers other than cans

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13.1 Introduction and background

The market for thermally processed foods presented in containers other than the traditional can is, in commercial terms, a relatively young one. All common packaging materials, board, glass and plastics as well as metal, are now represented in this market, the most recent entry being plastics.

In the case of these heat-stable high-barrier plastics containers both Maskell (1991) and Seldman (1992) give good accounts of the history of this market, showing how the first products were test marketed as recently as 1983 and how it was not until 1987/88, when a number of both major branded food manufacturers (General Foods, Batchelor Foods) and high street retailers (Boots, Marks & Spencer) entered the market, that the area started to grow. Growth however has been rapid, and, for the most part, sustained through the 1980s and into the 1990s. This is demonstrated quite vividly by figures on the amount of retortable plastics barrier containers sold in the UK over the period 1988–1992 (Wendt, 1992) (Table 13.1). Other figures reflect this trend with the area continuing to show a value growth of around 8% pa to an estimated total value of £26 million in 1992 (Anon, 1992c).

Other major packaging formats for ambient stable moist/liquid products are the board/foil laminate TetraPak and Combibloc containers, dominated by the fruit juice and dairy markets, and the glass jar.

Despite the fact that glass has a considerable history as the packaging for heat processed products (Appert's original experiments in 1809 used corked jars), usage has been declining until relatively recently. Fuelled by the growth in the pasta ('pour over') sauce market and more recently in the conversion of the 'cook-in' sauce market from cans and board/foil laminates to glass, the format has gained favour again, partly due to its 'green' image and recyclability.

The non-pasta sauce market in the UK started with the launch of a range of canned cook-in sauces under the RHM 'Homepride' label in 1974. The first launch in carton (Colmans) took place in 1987 and since then growth has been rapid (around 20% pa in terms of volume) with the

Table 13.1 Growth of retortable plastics barrier containers in the UK (1988–1992)

Year	1988	1989	1990	1991*	1992*
Containers used (million units)	5.0	9.3	19.5	24.0	30.7

*Estimated.
Source: Wendt, 1992.

market having an estimated market value in the UK of around £60 million (Anon, 1992a). The pasta sauce market is somewhat younger having started in the UK with the launch of Campbell's 'Prego' range in 1981. This market is almost entirely glass based and has also shown very rapid growth (21% volume increase in 1991) with an estimated UK market value of £65 million in 1992 (Anon, 1992b).

None of these product areas has any appreciable showing in cans. This review therefore, focuses on these product areas and concentrates on the shelf life of heat processed foods, packed in plastics packaging. It is the case however that many of the observations and procedures will be equally applicable to other packaging formats, differences in shelf life between packaging formats being related, in the most part, to variation in permeability of the actual packaging materials and their sealing systems to external factors affecting product stability, primarily light and oxygen.

13.2 Product groups and their characteristics

The products covered under the heading of this chapter can all be described as 'meal components in sauce'. The reason that such a blanket description can be applied to pasta sauces, stir fry vegetable mixes, ready meals and so on is that all of these products need the application of an accurate thermal process to provide stability while optimising quality. This requirement dictates that, although the ratio of sauce to components may vary and the components themselves be many and diverse, the presence of a continuous liquid phase is common to all.

In all these moist, ambient-stable, processed food systems a combination of an applied heat process, product formulation and suitable packaging is used to confer microbiological safety and stability by either (a) producing and maintaining a microbiologically sterile system or (b) reducing microbial counts to an acceptable level and producing and maintaining a bacteriostatic system.

In the case of the product groups covered in this chapter these two

categories are usually differentiated by the pH of the foods concerned. High pH products (pH $\geqslant$ 4.5) are generally cream sauces, gravy based meals or sauces, or occasionally low water activity 'dry' packed meal components such as potato products. Low pH products (pH $\leqslant$ 4.5) are generally tomato based or of the 'sweet and sour' type with high levels of natural acidulants such as vinegar, fruit juice or fermented sauces.

High pH products have to be subjected to a thermal process sufficient to destroy all microorganisms and in general terms this means a heat treatment equivalent to at least 3 minutes at 121°C (F_0 = 3). For low pH foods, with a pH of 4.5 or less, a less severe thermal process will achieve ambient stability as the pathogenic organisms of greatest concern – *Clostridium botulinum* – cannot grow under these conditions.

These basic microbiological rules hold regardless of whether the product is packed in glass, high-barrier plastics or foil laminates and determine that quality change on storage due to microbial activity (i.e. spoilage) should not be a shelf life factor in these products.

13.3 Specific factors affecting shelf life

In thermally processed ambient-stable foods deterioration is restricted, for the most part, to that caused by (i) enzyme activity, (ii) chemical reaction and (iii) physical breakdown of components.

13.3.1 Enzymic activity

In general terms the thermal processes to which these products are subjected during manufacture are sufficient to inactivate all enzymes and it is rare for residual enzymic activity or enzyme regeneration to cause storage problems.

The possible exception to this is in the case of UHT High Temperature Short Time processes. Here enzyme reactivation has been noted, the most commonly quoted example being the reactivation of alkaline phosphatase, lipase and protease in UHT processed milk (Kikakis, 1986). Possible storage effects are gelation due to protease activity and the introduction of off-notes in the flavour due to lipase action on milk fat. Such problems are however uncommon and are rarely if ever observed in retort processed systems due to the longer periods of heating involved.

13.3.2 Chemical changes

Chemical changes that take place in such systems are those related to either oxidation, non-enzymic browning (i.e. Maillard reaction) or resulting from nutrient breakdown.

13.3.2.1 Oxidation. Oxidation reactions are many and complex. They can use either headspace oxygen, trapped oxygen or free radical oxygen released by enzymic activity or thermal treatment. They can be initiated photochemically; they are, in common with all chemical reactions, very dependent on temperature and time, and are often catalysed by common food constituents such as trace metals. The results of these reactions are similarly varied but most commonly are observed as 'off' colour and flavour development resulting from the oxidation of lipids, colours and other reactive species. Under normal ambient storage conditions, i.e. 15–25°C, oxidation reactions are probably the most common cause of quality deterioration during storage.

Mogensen and Poulsen (1980), in a study comparing different packaging materials on the shelf life of UHT milk, showed a strong dependence of flavour quality on storage time and temperature and, most significantly, whether or not the packaging was permeable to oxygen.

Colour changes however, although similarly dependent on storage temperature and time, did not show this link with oxygen and were concluded to be related to non-enzymic browning reactions (see below) rather than oxidation reactions. Trammell *et al.* (1986) demonstrated similar results for pasteurised orange juice where both the loss of ascorbic acid and, in this case, browning could be related to initial headspace oxygen concentration but where flavour change could not be related to oxygen concentration, implicating once again, Maillard type reactions.

13.3.2.2 Non-enzymic browning or Maillard reaction. In general terms this reaction takes the general form of a condensation reaction between amino acids and reducing sugars and has the potential to occur in any system where these two substrates are present. Although the Maillard reaction is extremely complex the factors which control it are reasonably well understood. The application of thermal energy has a complex effect on the reaction. In general, as with all chemical reactions, heat accelerates and in many cases initiates the reaction, but due to the complexity of the sequence of the reaction steps the relationship is not a clear one (Benzig-Purdie *et al.*, 1985). Moisture content is an important controlling factor. Very low (approaching 0%) and very high (greater than 90%) moisture systems show little or no non-enzymic browning, but few foods fall into these categories. pH has an inhibitory effect on the Maillard reaction when low and accelerates the reaction when high but there is little or no effect between pH values of 3 and 8, i.e. at the pH values of most foods. The nature of the substrate materials also affects the reaction. Proteins are less reactive than pure amino acids, polymeric carbohydrates such as starch do not take part in the reaction but pure reducing sugars such as lactose are very reactive. Many other chemical constituents of foods have either positive or negative effects on non-enzymic browning and this

complex series of reactions can affect food quality in three ways. Firstly it can produce undesirable 'off'-colour and flavour – the brown discoloration and bitter notes in sterilised milk are usually quoted as an example of this. Secondly the condensation reaction can lead to a reduction in nutritive quality of the food as it consumes carbohydrate and amino acids, and thirdly it has been suggested that some of the compounds produced by the latter stages of the reaction may be anti-nutritional in nature.

13.3.2.3 Nutrient breakdown. Loss of nutrients from a processed food is strongly influenced by the severity of the applied heat process and by the time and temperature of storage. The effects of thermal processing have been well reviewed by Harris and Karmas (1975) who provided a detailed compilation of available kinetic data relating rates of loss of a range of nutrients to thermal processes. A general conclusion is that 'High Temperature Short Time' (HTST) processes and low storage temperatures favour nutrient retention but that all processed foods exhibit some degree of nutrient loss. Similarly Kramer (1977) reviewed the available literature on the effects of storage on fresh, frozen and canned foods and concluded that in all cases the lower the storage temperature the better for not only the nutrient retention, but also the 'aesthetic' properties of the food, i.e. appearance, taste, and so on.

13.3.3 Physical breakdown

Although there is the potential for physical change in many of the components of thermally processed ambient stable products, e.g. texture change in meat, softening of vegetable components, these are rarely a problem. The major reason for this lies in the fact that the initial heat process to which the food has been subjected, particularly if this is a sterilisation process, has already effected far more change on the system than that possible by even the most elevated storage time/temperature combination.

The two main physical factors influencing the shelf life of these foods relate therefore to the continuous aqueous sauce phase rather than to the discontinuous component phase and to two phenomena, namely starch retrogradation and emulsion breakdown.

13.3.3.1 Starch retrogradation. As previously mentioned most thermally processed foods contain an appreciable percentage of water-based sauce or gravy both to add taste to the other components and to facilitate the heat processing operation. In many cases the texture of this sauce component is controlled by the addition of thickening agents such as edible gums and starches. In actual fact careful selection of these thickeners can also improve the efficiency of the applied thermal process by providing a

system with heat transfer properties optimised for each stage of the process through control of the temperature/viscosity profiles (Whistler and Paschall, 1967). The most commonly used thickeners are those best suited to this purpose – chemically modified starches.

A great deal has been written regarding the physical and chemical nature and behaviour of starch and it is not within the remit of this chapter to go into this topic in any detail. For a very complete reference work on this subject the multi-volume treatise *Starch: Chemistry and Technology* by Whistler and Paschall is recommended. There is one property of cooked starch systems which is of importance in the storage stability of many ambient-stable moist foods and that is the phenomenon known as 'retrogradation'. To understand this phenomenon a little further explanation of the physico-chemical properties of starch is necessary.

Starches are the favoured thickeners for savoury foods because of the short and clean texture generally desired in such systems, but, because of the relatively delicate nature of cooked native starches such as cornflour or potato starch, chemical modification is required to give the starch the necessary stability to processing.

In most applications the thickening and texture-giving properties of starch are due to its presence in the hydrated form as swollen granules entrapping concentrated aqueous biopolymer solutions. These biopolymers comprise repeating anhydroglucose units either linear in nature and connected by alpha 1-4 glycosidic links (amylose) or with a branched structure, the anhydroglucose units being again connected by alpha 1-4 links but also having an alpha 1-6 link at selected sites (amylopectin). In the presence of heat and water these glucose polymers move from a crystalline to a solution state, binding water of hydration and 'swell'. Starches are chemically cross-linked to 'toughen' the granules and to prevent (or at least reduce) granule disintegration through the application of heat, shear, extremes of pH or ionic change. Cross-linking is achieved by treatment of the native starch with di- or polyfunctional reagents capable of reacting with the hydroxyl groups in and between both the amylose and amylopectin molecules to form chemical bridges which restrict swelling of the hydrated polymers and hence of the starch granules.

'Retrogradation' is a phenomenon related to the tendency for dissolved starch molecules, particularly the linear amylose molecules, to move from a disordered to a more ordered state, but one quite different from that found in the uncooked starch granules. In solution the hydroxyl groups on parallel amylose molecules exert attractive forces (hydrogen bonding) and molecules line up into a network structure. This restructuring in solution manifests itself initially as the formation of a gel structure but with time, or when exacerbated by freeze–thaw cycling, the gel contracts and water is expelled (so-called 'weeping'). In extreme cases this 'dehy-

dration' will result in amylose being precipitated out of solution as insoluble, high melting point granules, giving rise to a rough or grainy texture. This phenomenon is not entirely restricted to amylose. Amylopectin will also exhibit a form of retrogradation, giving rise to weak gels; but the strength of these is weak and as the melting point of crystalline amylopectin is below the serving and eating temperature of most savoury products, this is not considered to be a problem.

The 'toughening' of the starch granules or immobilisation of polymeric material by chemical crosslinking also serves to reduce the amount of free starch molecules, in particular the amylose, which leaches out of swollen or broken granules and hence acts to reduce the chance of retrogradation. This is not a total solution however, since the percentage of starch molecules which can be cross linked without giving rise to unacceptable reduction in thickening power of the starch is low – a maximum of one crosslink per 100 starch molecules and often as low as one link per 2000 molecules. This still leaves a very high percentage of 'free' molecules and an appreciable risk of retrogradation taking place, particularly in systems which have been subjected to extremes of heat and shear, e.g. sterilised systems. In order to overcome this, most modified starches are based on native starches low in amylose (and hence high in amylopectin) – the so-called waxy starches – and a second modification is applied to remove the unacceptable 'long' or 'slimy' texture associated with amylopectin.

In most cases therefore the tendency for heat processed foods to exhibit retrogradation has been formulated out but the growing need for 'clean labels' and the progressive removal of chemical additives from foods is forcing a return to native starch and flour based systems which may well result in a resurrection of the problem.

13.3.3.2 Emulsion stability. Many heat processed foods, particularly those containing cream style sauces, contain appreciable levels of fat in the form of an oil-in-water emulsion.

In order to maintain the fat in this state the system requires the presence, at the oil/water interface, of an emulsifier – a material with both hydrophilic and lipophilic properties, which stabilises the fat droplets against coalescence. If this material is not present at a sufficiently high level to stabilise the emulsion throughout the thermal process, or if its emulsifying properties are damaged by the applied heat, the emulsion will 'break' and the oil and water phases will separate into two distinct layers.

The most common emulsifiers used in food systems are proteins – particularly milk proteins – and fat derivatives, both naturally occurring and synthetic, where hydrophilicity is derived from the presence of polar species attached to the non-polar glyceride moieties.

Fat-derived emulsifiers are in general stable to the time and temperature combinations that most conventional thermally processed foods experi-

ence. Proteins are considerably more heat labile, denaturing (changing structure) and changing functionality in the presence of heat. Proteins are also sensitive to chemical factors such as pH and free ion concentration, and, under certain conditions in aqueous solutions will, often as a function of time, denature and change in functionality. The most common visible result of protein denaturation is a loss of emulsifying properties, reflected in emulsion breakdown, and a textural change, such as gelation or granularity, in the aqueous phase. Any or all of these changes may be important factors in shelf life determination.

13.3.4 Other factors influencing shelf life

Two other factors may affect the shelf life of thermally processed ambient stable foods, both of which primarily influence the flavour of stored products. Firstly, there is the possibility, particularly in plastics laminate packaging but also to a lesser extent in other laminate materials, of flavour migration into the packaging material or partitioning between product and packaging and secondly, the much more common effect of flavour transfer between product components.

The latter effect is only really a problem in mixed component systems (such as fruit salads and ready meals) where, over a period of time, individual components start to lose their own flavour characteristics and to take on an 'average' taste. It is rare for this phenomenon to produce truly negative quality attributes but, in order to maintain high quality in these products, it is often monitored as a guide to establishing optimum shelf life.

Flavour and colour migration into packaging tends to be more of an aesthetic problem than a quality issue. The levels of loss of flavour and colour into the packaging are very low and are more likely to result in discoloration of the inside of the pack rather than a significant loss of colour or flavour in the product. What is of more concern is the possibility of constituents of the packaging material, e.g. plasticisers, migrating into the food. Of particular concern regarding the potential quality issues associated with the presence of these materials in processed foods are systems where the food has been subjected to high or prolonged thermal treatment whilst in contact with the packaging material, e.g. during a post-packaging pasteurisation or sterilisation process or during regeneration for consumption in either a conventional or a microwave oven.

In 1973 the EEC adopted a resolution to initiate a programme for the harmonisation of legislation on food contact materials in order to remove technical barriers to intra-community trade and to protect consumers from any risk arising from the migration of packaging components into foods. The first part of the legislation on this issue related to plastics was

completed in 1990 and issued as Directive 90/128/EEC, the so-called 'Plastics' Directive.

The legislation prescribes in some detail test methods for measuring the migration of packaging material components into foodstuffs and the maximum permitted levels of these components. It further spells out the nature of the tests required to be made with reference to the food simulants which should be used to replace actual foods, the temperature regimes to which the test materials should be subjected and the number of replicates/frequency of testing.

Although this type of testing is unlikely to form part of shelf life evaluation, as all packaging or potential packaging materials should have already passed through this protocol, the methodologies included within it can often be usefully applied to the determination of specific storage problems, e.g. related to flavour loss or colour migration into packaging, and the reader is directed to the official EC publications for details.

13.4 Determination of shelf life

From the information given above it can be seen that the storage changes which dominate in heat processed ambient-stable foods such as sauces and ready meals are mainly changes in flavour and colour. Textural changes can occur in such foods but by and large these are insignificant when compared to the textural changes imposed on the system by the initial thermal process. Changes in colour and flavour, therefore, are the major determinants of shelf life. This then governs the way in which changes are monitored and shelf life is set.

Textural change is limited and if it does occur, is usually restricted to the aqueous phase. Rheological measurements, such as the measurement of viscosity under specific conditions, can be used to monitor such change. In most instances however, if such change is to be a controlling factor in shelf life determination, it will be easily recognised without the need for instrumental analysis.

Colour change also tends to be relatively easy to recognise as a shelf life determinant but in this case instrumental measurement is favoured as a means of quantifying the change and finding the point of unacceptability.

Flavour change is the most common and most difficult shelf life controlling factor to quantify in thermally processed ambient-stable products. Instrumental analysis of flavour change is very difficult. Food flavours, particularly natural food flavours, are complex and subtle, often comprising many hundreds of chemical constituents, many at extremely low levels. Many and various attempts have been made to measure flavour. Chromatographic methods such as HPLC (high performance liquid chromatography) and GC (gas chromatography) have been widely used

(Barberio, 1986), both as means of producing a 'fingerprint' of the flavour and, when coupled with mass spectroscopy, as means of identifying change in specific aroma compounds. Experience suggests however, that such techniques are best suited for the examination of specific problems (for example, the plasticiser migration problem outlined above), and are not suitable as quality control tools to be used in the setting of shelf life criteria.

In summary therefore, the best approach to use in the storage testing and shelf life determination of thermally processed ambient-stable foods is to rely on the human senses, using carefully controlled sensory analysis techniques, augmenting these, if necessary, with analytical or instrumental analyses.

The following sections describe a protocol for the storage, sensory testing and shelf life determination of an ambient-stable pasta product, a protocol which can be adapted to suit any of this type of product.

13.4.1 Storage protocol

The two major factors to take into consideration in setting up a storage trial for any product are the anticipated time and temperature of storage.

13.4.1.1 Time. As previously mentioned the microbiological storage life of thermally processed products that have been processed and handled correctly is indefinite; which is why the determination of shelf life is based on the maintenance of acceptable sensory quality. A realistic assessment of the period between manufacture and consumption for this type of product gives a total life of 18 months. This figure is based largely on experience with other ambient-stable products, e.g. canned products, jams and preserves and dry mix products, and probably errs on the side of caution for this new generation of thermally processed foods. Although it is known from in-home audits that canned and dry mix products may reach this age (or even older) before consumption, it is likely that there is less chance of this being the case with modern packaging formats, particularly with respect to the plastics laminate pack, the 'technicalities' of which are less well understood by the consumer. Nevertheless, based on this assessment, storage testing is generally set to run for a minimum of 12 months. 'Take offs' – the intervals at which samples are removed from storage for analysis – are usually scheduled at monthly intervals although it is common practice to sample at, for example, 0, 1, 2, 3, 6 and 12 months, only testing at the remaining take-off points if problems are becoming apparent.

13.4.1.2 Temperature. It is important to remember that an estimate of the temperature of storage of ambient-stable products is probably very

different from the average ambient temperature they actually experience in practice. Temperatures within the distribution chain are likely, in Northern Europe, to range from zero in an unheated warehouse at night to in excess of 30°C in a truck in mid-summer. Because of this it is common to store at two temperatures – an 'average' temperature, usually taken as 25°C, and an 'abuse' temperature, usually taken as 35°C. It must also be noted that these are Northern European criteria. For tropical climates higher temperatures, e.g. 30°C average, 40°C abuse are usually used.

One final point regarding temperature of storage is that if it is known that the product is likely, when in the distribution chain, to experience severe and regular temperature cycling, this should also be built into the storage protocol.

13.4.1.3 Other factors. Two other factors may need to be considered when setting up a storage protocol. Firstly, there may be a need to consider and allow for the effect of light. This is certainly the case for products packed in glass or other transparent materials but may also be important for products packed in translucent plastics. If light is a factor, it is normal to set up two parallel exercises, with one set of samples being stored under suitable illumination, and a control set being stored in the dark.

Secondly, certain packaging materials are permeable to water vapour. This should not be the case for the materials used for thermally processed foods but needs to be taken into consideration if the protocol is to be extended, e.g. to dry mixes. In the case of moisture vapour transfer being suspected as a contributing factor to storage stability, a control experiment needs to be set up storing samples in both high and low relative humidity environments.

13.4.2 Sensory analysis

The definition of the shelf life of a food product in respect of sensory changes as a function of storage is based on the answering of one or more of the following questions:

1. How long can the product be stored without noticeable change in its sensory attributes?
2. How do sensory attributes change on storage?
3. How long can the product be stored before changes in sensory properties render it unacceptable?

The first two questions relate to objective analysis of the product – no qualification is required and no subjective assessment of quality is required. If question (1) is used to set shelf life a simple 'yes/no' response

to a discrimination test will suffice. There is no need for highly trained sensory assessors but a large number of people are required to ensure a statistically robust answer. Triangular tests and paired comparison tests will give a simple yes/no answer; ranking and magnitude estimation tests will add some measure of the degree of difference.

If question (2) is used then shelf life will either be estimated from determining the point at which selected sensory attributes of the product approach predetermined unacceptable levels or by the application of a secondary test which will answer either question (1) or (2). A descriptive test based on assessment of samples by a highly trained sensory panel is required to provide this sort of 'magnitude' data and a profiling method such as Quantitative Descriptive Analysis (QDA) is often used.

The third question is rather different. Changes in sensory properties are expected and a subjective assessment of the degree of change considered acceptable is required. Typical tests are based on either comparison, presenting paired samples (e.g. the test sample against a control) and seeking an absolute preference, or ranking, presenting samples either singly or in sequence and seeking a degree of preference. For this latter approach the 'Hedonic' rating scale, derived by Peryam and Pilgrim (1957) in the 1950s is still the most widely used (Figure 13.1).

If this approach is used it is most important that the panel be composed of untrained 'consumers' – to ensure a subjective rather than an objective assessment – and number at least 50 people to ensure statistical reliability. This approach is commonly used as an 'in-house' evaluation technique and in this case it is unlikely that the panel will truly represent the consuming public. Sensory quality assessments of this sort should therefore be regarded as giving guidance rather than absolute results. The only way to obtain the latter is via full consumer research.

Detailed guidelines for all of the methodologies outlined above together with a wide range of less widely used and more sophisticated tests are given in the book *Guidelines for Sensory Analysis in Food Product Development and Quality Control* (Lyon *et al.*, 1992). For our test case, the

Nine point Hedonic rating scale

Like extremely
Like very much
Like moderately
Like slightly
Neither like nor dislike
Dislike slightly
Dislike moderately
Dislike very much
Dislike extremely

Figure 13.1 Nine point Hedonic rating scale (Peryam and Pilgrim, 1957).

ambient-stable pasta in sauce product, we will focus on the use of QDA to produce sensory 'fingerprints' coupled with a hedonic ranking to obtain estimates for both shelf life and the sensory characteristics which govern it.

13.5 An example – pasta shapes in savoury tomato sauce

13.5.1 Protocol

The test product is a simple ready meal consisting of pasta shapes in a minced meat and tomato sauce, the following being a summary of the manufacturing and distribution process.

> The product is packed, as a two shot fill (pre-cooked drained pasta followed by hot sauce) into preformed polypropylene trays, lidded with a polyethylene/aluminium foil laminate and retort sterilised to a F_0 value of 3.
>
> The product is for distribution at ambient, the individual trays being overwrapped with a printed paperboard sleeve and shrink-wrapped in dozens in cardboard trays. The desired storage life (manufacture to consumption) is one year.

From this information a storage protocol can be developed to determine the shelf life of the product.

1. The product is fully sterilised so that microbiological stability will not be a shelf life determinant. Past experience suggests however that the sauce containing meat and tomato may give rise to colour changes on storage and further, it is possible due to the acidic nature of tomato, that changes in meat texture may occur. Furthermore pasta tends to soften in time due to water pick-up and starch loss, so textural changes in both pasta and sauce are possible. This combination of possible changes suggests that a QDA test, coupled with a simple monadic liking test (i.e. samples are presented one at a time) is probably the best approach for this product. Although instrumental measurements may be considered to provide further information on colour change, experience also tells that the heterogeneous nature of the product (coarse textured sauce, meat particles, pasta) will give poor reproducibility. Colour analysis will therefore have to rely on sensory estimation.
2. The product will be stored, transported and displayed at ambient temperatures. A Northern European environment is assumed and storage trials at +25°C and +35°C will be conducted, in order to assess the product's tolerance to abuse conditions. A control sample will be stored at +2°C, the assumption being that any change over the storage trial at this temperature will be minimal.
3. The product is packed in an opaque primary packaging and over-

Table 13.2 Storage protocol for pasta in savoury tomato sauce

Take off point	Date	Storage temperature	Testing required	Number of samples required
Time zero	Jul 1993	n/a	QDA + Colour	10 + 2
One month	Aug 1993	+2°C, +25°C and +35°C	QDA + Colour	10 + 2 for each temperature
Two months	Sep 1993	+2°C, +25°C and +35°C	QDA + Colour	10 + 2 for each temperature
Three months	Oct 1993	+2°C, +25°C and +35°C	QDA + Colour	10 + 2 for each temperature
Six months	Jan 1994	+2°C, +25°C and +35°C	QDA + Colour	10 + 2 for each temperature
One year	Jul 1994	+2°C, +25°C and +35°C	QDA + Colour	10 + 2 for each temperature
Eighteen months	Jan 1995	+2°C, +25°C and +35°C	QDA + Colour	10 + 2 for each temperature

wrapped with a paperboard sleeve. For this protocol, the packaging is assumed to be lightproof and there is no need to build a light sensitivity test into the trial.

4. The product is expected to have a storage life of one year. To add a margin of safety, storage trial will continue for 18 months. Take-offs however will be staggered – time zero, one month, two months, three months, six months, one year and eighteen months but a 'safety factor' of extra samples will be included to allow for intermediate take-offs and testing if necessary.

The test protocol can therefore be summarised as in Table 13.2. This protocol allows the scheduling of the testing and gives an estimate of the total number of samples required. The ten samples retained for the QDA analysis at each 'take off' point is based on the need for 40 replicates and the assumption that each pack will provide four portions. It can be seen that a minimum of 72 samples should be stored at each temperature with a further 12 samples available for the time zero testing. Bearing in mind that these are minimum figures, the number should be increased by 50% for the storage samples and at least doubled for the time zero samples to allow for the training of the taste panel, i.e. a total requirement of some 350 samples.

13.5.2 QDA/Liking testing

For the purpose of this example it is assumed that a suitable sensory analysis facility is available and that an experienced taste panel has been selected. If this is not the case then the reader is directed again to the book *Guidelines for Sensory Analysis in Food Product Development and Quality Control* (Lyon *et al.*, 1992), where the authors give in some detail

Table 13.3 Attribute list for pasta in savoury tomato sauce

Pasta	Code	Sauce	Code
Colour intensity	PASCOL	Thickness	THICHN
Intactness	INTACT	Colour intensity	SAUCOL
Firmness	PASFIR	Glossiness	SAUGLO
Smoothness	PASSMO	Smoothness	SAUSMO
Sliminess	PASSLI	Chewiness (of meat)	CHEWIN
Starchiness	PASSTA	Overall strength of flavour	FLAVST
		Tomato flavour	TOMFLA
		Meat flavour	MEAFLA
		Herbs	HERFLA
		Spiciness	SPIFLA

the requirements for the design and development of such facilities and panels.

The first step in the QDA methodology is to develop a descriptive vocabulary to describe the sensory attributes of the product in question. This is done as a group exercise and after due discussion an attribute list is generated. This lists all the sensory parameters, appearance, aroma, flavour and texture, by which the assessors can describe any given sample in terms of a set of scores. Table 13.3 gives the full attribute list for the test product and Figure 13.2 shows the scoring sheet relating to the pasta attributes.

With these attribute lists and a score sheet a trained assessor can produce an accurate and reproducible 'fingerprint' of a sample. To ensure statistical confidence each sample is tasted blind in the order of 40 times. A QDA taste panel usually has 12 to 15 assessors and each assessor is presented randomly with each sample two or three times. A carefully randomised design for sample presentation coupled with internal replication and random coding of samples ensures that the sample analysis is free from order effects and other subjective parameters.

As stated previously, QDA analysis is, if correctly applied, entirely objective. In order to assess changes in product quality, an acceptability question, based on hedonic rating, is added to the end of the QDA scoring sheet.

Each storage sample is tested at each take off and an average score calculated for every sensory attribute. With this information a sensory 'fingerprint' can be constructed for each sample. Typically this information is represented graphically as a simple line or bar graph showing sensory scores as a function of attribute. Using this method a graphical representation of the sensory properties of the product may be produced and comparisons made between samples by simply overlaying plots. Figure 13.3 represents sensory plots for the control sample stored at $+2°C$ compared with the sample stored at $+35°C$ after one year.

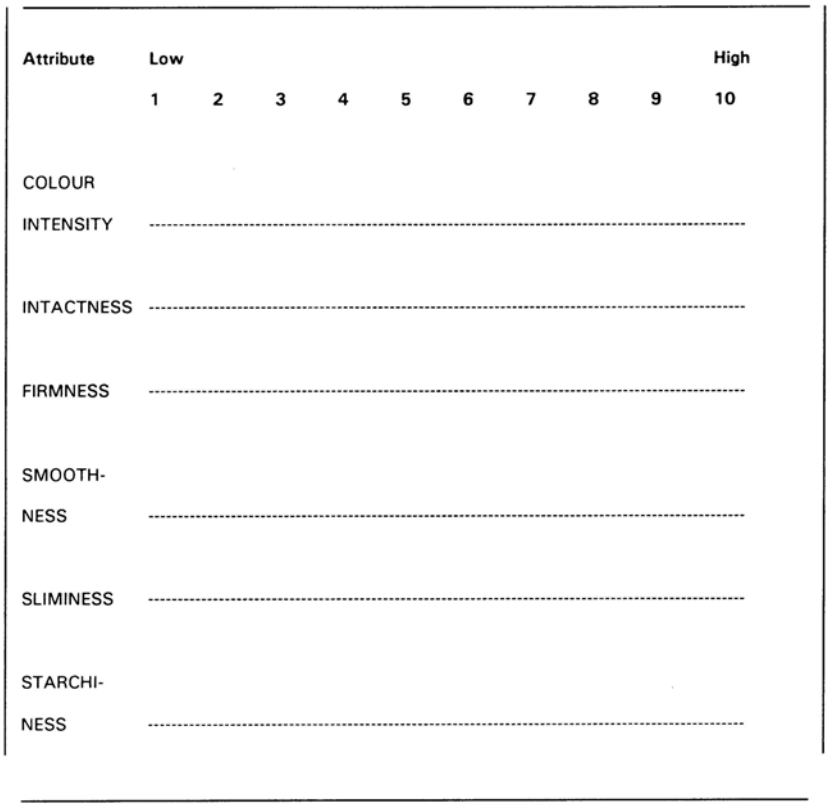


Figure 13.2 Scoring sheet for pasta.

Although these graphical representations show changes in sensory properties quite clearly they do not, in their own right, give any estimate of the statistical significance of these differences. It is usual therefore to couple this simple graphical approach with a statistical analysis of the raw data. Once again there are a number of methods available, which mostly rely on the analysis of variance to give a measure of confidence intervals between samples on the basis of their individual attributes. Such information may be superimposed on the plots, using asterisks to highlight those attributes which show significance at the various confidence limits.

Similarly this information gives no indication as to the effect that any changes are having on product acceptability. The liking scores, averaged in the same way from the hedonic data, give this information (albeit in a crude form). Such information is usually expressed in the form of a simple line graph as shown in Figure 13.4.

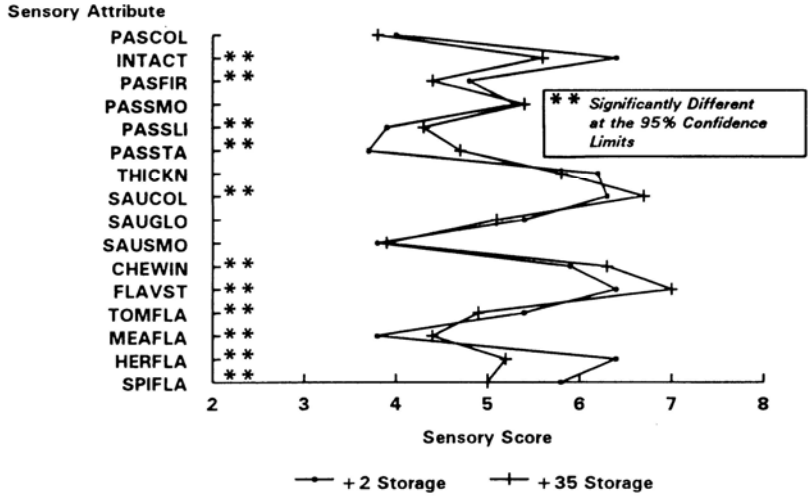


Figure 13.3 Comparison of sensory scores for 'control' and 'abuse' stored samples. •, +2°C storage; +, +35°C storage.

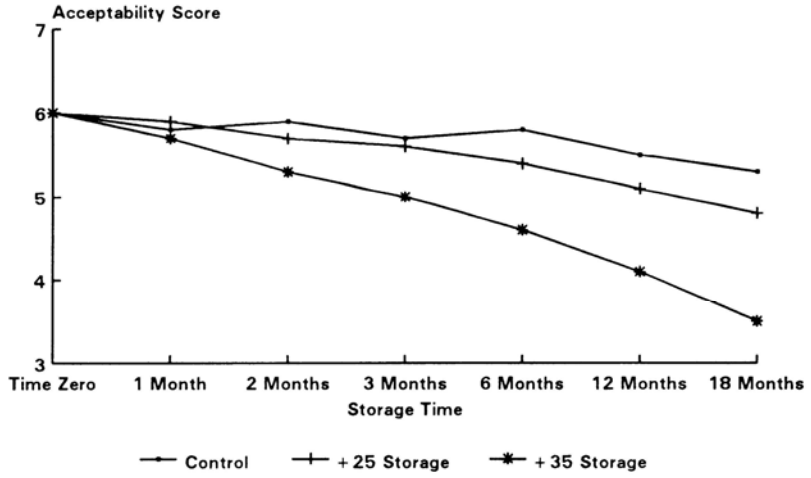


Figure 13.4 Hedonic liking scores for stored samples. •, Control; +, +25°C storage; *, +35°C storage.

13.5.3 Interpretation of results

13.5.3.1 Basic analysis. The simplest way of using the results produced by a storage study such as this is to use the hedonic liking scores to determine product shelf life and the sensory analysis results to determine which factors are controlling the shelf life.

To determine shelf life from acceptability data a threshold liking score is set, either by a suitable 'expert' panel or from data gained from full

consumer testing. The shelf life is set based on the period and conditions of storage which will reduce the acceptability score of the product to this point.

Assuming all other factors being equal, i.e. that the sensory and acceptability tests have been properly controlled and carried out, any changes in liking must be linked to changes in sensory properties. Sensory data can therefore be used to determine the factors responsible for changes in acceptability by analysing the sensory data for statistically significant changes in attributes.

In the above example expert assessors have set a threshold acceptability score of 5.0 for the product. Shelf life for the product stored under normal conditions is therefore between 12 and 18 months but any temperature abuse will shorten this considerably.

The major attribute changes as a function of storage time, and temperature detected in the sensory analysis can be seen to be related to pasta texture (intactness, firmness and starchiness), sauce appearance (colour, glossiness) and flavour (all attributes), and meat chewiness. Although it is not possible to draw definite conclusions from this analysis it is likely that the loss of 'freshness' of flavour from the sauce coupled with the loss of texture in the pasta are the prime determinants of shelf life and the first problems to be addressed if a longer shelf life is to be sought.

13.5.3.2 Predictive analysis. This simplistic approach to the determination and rationalisation of shelf life from the interpretation of storage results is usually sufficient for most products. This is particularly the case where the foods, such as the example in this chapter, have relatively short shelf lives and where storage conditions, although variable, are reasonably well controlled. In the case of products with longer shelf lives, or where for example storage temperatures may be subjected to wide variations, shelf life prediction may be preferred to simple shelf life determination. This approach is based on the building of quality kinetics equations, which are derived from detailed study of the effects of a carefully controlled matrix of storage parameters (time, temperature, light and so on) on the perceived quality of a specific product. This information allows the construction of a predictive equation which includes these parameters as variables and which can be used to model and predict quality performance on storage. This approach to shelf life testing has been the subject of much and varied work and a detailed review is beyond the remit of this chapter. There may however be occasions when such an approach will need to be considered and interested readers are directed to *An Illustrated Approach to Food Chemistry* (Labuza, 1985) for a complete review of the subject.

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14 Ambient-stable sauces and pickles

A.A. JONES and C.M.D. MAN

14.1 Introduction

The product group of sauces and pickles comprises a very wide range of traditional as well as more modern fruit/vegetable products. To examine these products will necessitate subdividing the group and dealing with each subgroup in turn. Different subgroups have their own particular modes of deterioration but they all rely wholly or primarily on the use of acetic acid for preservation.

In this chapter, sauces are taken to include the emulsified sauces such as mayonnaise and salad dressings, and the non-emulsified condiment sauces such as tomato ketchup, brown sauce, mint sauce, and so on as well as the sweet sauces such as topping syrups and fruit-based sauces. Pickles are interpreted to include those products traditionally regarded as pickles, such as pickled onions, pickled cabbage, pickled gherkins and so on and also products which are in the grey area between pickles and sauces, such as sweet pickles, piccalilli and chutneys.

The major similarity among all these products, as pointed out earlier, is that traditionally (albeit less so these days) they belong to the category of compositionally-preserved foods since they rely in the main on acetic acid (or sugar) for self preservation. In more recent times, dependence on the traditional method of preservation has been reduced, due to consumer demand for less acidic or less sweet products, making some of these products potentially vulnerable to microbiological spoilage. Consequently the use of alternative preservation methods, such as the inclusion of chemical preservatives (e.g. the organic acid preservatives), thermal processing (e.g. pasteurisation), and aseptic processing and packaging has increased. Moreover, greater emphasis has been placed increasingly on preventive tools such as the one based on the 'Hazard Analysis Critical Control Point' (HACCP) system, for the assurance of safety and quality in foods (CFDRA, 1992).

It is intended to examine briefly the scope of sauces and pickles and in more detail the main factors affecting shelf life and the way they can influence microbiological as well as physico-chemical changes in these products. Once the relevant shelf life determining factors and modes of deterioration have been established, the exact methodology for shelf life determination usually follows logically. Current practice in the shelf life

determination of these products, including the use of challenge testing and mathematical models, will be outlined together with a worked example. Reference will be made to previous chapters regarding areas which should be considered but have already been covered elsewhere in this book.

Finally a section will examine current developments within this product sector as well as the industry at large, which may have an impact on the shelf life of these products and the methods by which their shelf lives are determined in future.

14.2 The products

As discussed in the introduction, this product group comprises two major areas, of which sauces can be subdivided into at least three subgroups.

14.2.1 Sauces

Sauces may be defined as a range of formulated liquid or semi-solid food products, which when added to a food, alter or enhance the sensory appeal of that food, by adding richness of flavour and/or enhancing the mouthfeel.

Sauces may be used at the preparation stage of a meal. Marinades are examples of products which may be included in this category, where a certain degree of flavour needs to be introduced into the food before cooking. Sauces may be added at the cooking stage; products in this category range from simple sauces used for their flavour, such as chilli sauce, added to spice a meat dish (e.g. chilli con carne), to more complicated savoury cooking sauces such as creamy mushroom sauce, which when added to a basic commodity such as chicken, converts it into an exotic recipe dish. These sauces also include the 'make-a-meal' and pasta sauces. The main subgroup is represented by the 'pour-over' sauces which are added to a complete meal as an accompaniment (e.g. a salad meal or a convenience food such as pizza) in order to enhance or alter its sensory characteristics according to the consumer's preference. This subgroup of sauces is by far the biggest subgroup and includes the emulsified salad dressings (e.g. mayonnaise, salad cream, French dressing and so on), other emulsified sauces containing particulates (e.g. sauce tartare and horseradish sauce), non-emulsified sauces (e.g. tomato ketchup and brown sauce), the more exotic 'ethnic' type sauces (e.g. satay sauce) and fruit-based sauces for use with savoury products (e.g. cranberry sauce and red-currant jelly). 'Pour-over' sauces may also include the sweet (topping) and fruit-flavoured sauces used to add flavour and variety to desserts such as ice-cream, pudding and yogurt.

While sauces can be subdivided according to their culinary uses, from

the point of view of shelf life consideration, the approach that subdivides them into emulsified, non-emulsified and fruit-based sauces will be more useful. Also, for the purpose of this chapter, only ready-to-use ambient-stable sauces will be considered and no reference will be made to products preserved other than by acetic acid or by acetic acid in conjunction with a mild heat treatment.

14.2.1.1 Emulsified sauces. These, as their name suggests, are a group of sauces which consist of a viscous oil-in-water emulsion, stabilised primarily by egg yolk and normally containing vinegar. The level of oil ranges from the 80% plus level found in mayonnaise (this being very close to the maximum possible level of oil for an oil-in-water emulsion, higher levels would normally result in inversion to a water-in-oil emulsion), to the 'virtually oil free' sauces (e.g. low-calorie dressings) containing only a few percent oil. Emulsified sauces, therefore, may have widely varying oil contents, with the mouthfeel and texture possibly being modified by the inclusion of various fat mimetics or substitutes. The emulsion is usually formed by high shear mixing which reduces the oil into minute droplets of a uniform size distribution of about a few microns in diameter and distributes them evenly in the water phase of the product. Stability of the emulsion is then maintained by the inclusion of emulsifiers and stabilisers, either natural or chemically derived. Thus, a mayonnaise emulsion may rely solely on the emulsifying properties of the egg, or include additional ingredients such as polysaccharide gums (e.g. guar gum, xanthan gum) which are often used in commercially available mayonnaise.

Some of the emulsified sauces have been carefully defined, although definitions may vary from authority to authority. A mayonnaise, for example, has been defined by the European Codex as containing a minimum oil content of 78.5% w/w (from all sources) , and a minimum technically pure egg yolk content of 6% (WHO/FAO, 1989). It should be mentioned that, however, at the time of writing, this standard is being considered for international rather than regional status, and as part of the consideration, the details of the standard are also under review. The Association of the Mayonnaise and Condiment Sauce Industry of the EC, however, has agreed a voluntary standard for mayonnaise which requires a minimum oil content of 70% w/w and a minimum technically pure egg yolk content of 5% w/w (CIMSCEE, 1991). 'Technically pure egg yolk' is defined as the composition of egg yolk commercially available, and is assumed to contain about 25% of egg white. The US Standards define mayonnaise with yet another set of criteria.

Other than mayonnaise, there is currently no further legal or informal agreement for emulsified sauces within Europe, since the repeal of the UK's Salad Cream Regulations. However, in the USA, a salad dressing is

defined as 'an emulsified semi-solid food prepared from vegetable oils, vinegar, lemon juice and/or lime juice, egg yolk, and starchy paste'.

There are also emulsified sauces which contain added particulates. An example of these is sauce tartare, an emulsified dressing-based sauce containing particles of vegetables, usually gherkins and capers. Another sauce group which is important in the UK and Germany (but perhaps less well known in other countries) is that of the horseradish products. These again are based on salad dressing/cream, with the inclusion of grated horseradish (and perhaps turnip), giving a distinctively flavoured product for use with cooked meats and fish.

14.2.1.2 Non-emulsified sauces. These, as their name suggests, are non-fat based sauces, and are often manufactured by a process that may include a heating stage. Of such sauces, the classic example is tomato ketchup. The European trade association has put forward proposed standards for tomato ketchup, which require a minimum tomato solids content, and limit the addition of other ingredients (CIMSCEE, 1992). Other sauces falling within this subgroup include brown sauce, various other ketchups (e.g. mushroom ketchup), and the 'ethnic' style sauces that are now coming onto the market. Like emulsified sauces, they may be smooth, or contain particulates. The range of sauces is again very wide, but the technological problems associated with shelf life are very similar, as discussed later in this chapter.

14.2.1.3 Fruit-based sauces. These may be further subdivided into 'savoury' fruit-based sauces such as redcurrant jelly, cranberry sauce or the sweet confectionery sauces, such as flavoured topping syrups. The former group usually relies on sugar, and sometimes vinegar for preservation, having a high soluble solids content which inhibits most spoilage organisms. The process of manufacture often includes a heating stage which has a pasteurisation effect. The sweet topping syrups rely on a high soluble solids content and adequate thermal processing to inhibit microbial growth, with a low pH (e.g. due to the use of citric acid) also playing a minor part in maintaining the assigned shelf life.

14.2.2 Pickles and other related products

Pickles consist of vegetables preserved in vinegar or vinegar-based sauce, a traditional method of preservation which has been practised in many countries for centuries. Traditionally, pickling is one of the ways of ensuring that perishable fruit and vegetables would be available for periods outside their normal harvesting seasons. The major varieties consumed in the UK are pickled onions, pickled beetroot and piccalilli. The products are further divided into sweet and sour categories, with sour

pickles being the predominant category. Chutneys and relishes are frequently included in this category.

The traditional pickling process involves a number of stages: the brining of vegetables for storage, brine removal prior to preservation (freshening) and the preservation in vinegar or vinegar-based sauce (the pickling proper). The vegetables are often entire but usually processed to make them suitable for protracted storage. Thanks to efforts of J.C. Dakin and others for their work carried out at the Leatherhead Food Research Association over some 30 years, virtually all aspects of traditional pickle manufacture were scrutinised with the result that many practical problems were tackled and solutions found (Kilcast, 1984).

Chutneys and relishes are similar products, relishes often having smaller pieces of vegetables than chutneys. They basically consist of vegetable and/or fruit pieces suspended in a thick vinegar-based sauce. Their process of manufacture often includes a boiling/heating stage which reduces the moisture content of the mix, softens the fruit/vegetables and pasteurises the product. Examples of these products include familiar brands such as Branston Pickle, and products such as mango chutney.

14.3 Factors affecting shelf life

Many of the products within the area of ambient-stable sauces and pickles are well established and the specific factors that affect their shelf life are well known and documented. A very useful and comprehensive review on pickles and sauces is available and has recently been up-dated (Broomfield, 1993). Nevertheless, it is useful to review some of these factors as a good understanding of how they influence product shelf life will be important to product developers who are newcomers to this field as well as those who are trying to develop modern versions of these products.

14.3.1 Raw materials

The importance of quality and consistency of the raw materials used in the maintenance of the shelf life of sauces and pickles cannot be overemphasised. From a microbiological safety point of view, pasteurised egg is a must wherever it is used. All raw materials should be handled according to Good Manufacturing Practice (Anderson and Blanchfield, 1991) and if necessary, any sensitive ingredients should be decontaminated before use. Because of the long shelf life of products in this group, the quality of the raw materials is crucial if the assigned shelf life is to be met the first time and every time. For example, even the slightest signs of browning in the dehydrated horseradish flakes for use in various horse-

radish sauces could mean that the end product would not survive its stated shelf life as a result of colour deterioration.

14.3.2 Composition and formulation

This is perhaps the most important factor that influences the shelf life of ambient-stable sauces and pickles. This is because the exact composition and formulation of a product will have profound influence on possible changes that may occur during the storage of the product. These changes can be microbiological, physical, and chemical/biochemical in nature. Such changes, of course, can have safety and/or quality implications which are intimately linked to the shelf life of the product.

In the case of emulsified sauces (i.e. oil-in-water emulsions), the oil droplets are discrete and distributed throughout the continuous aqueous phase. This structure tends to preclude the spread of lipolytic spoilage organisms in the product. Furthermore, there is little indication that industrially produced oils (and fats) have a significant role to play in food-borne diseases. The oil phase can therefore be disregarded at least from a food safety point of view. For sauces (emulsified and non-emulsified) and pickles, therefore, the product safety determining factors are associated with the (continuous) aqueous phase. This aqueous phase contains the necessary ingredients that can support microbiological growth, e.g. sugars, water and certain micronutrients. However, it also contains invariably the components that either kill these organisms or inhibit their growth. Thus, the factors in the aqueous phase that determine the microbiological safety and stability of the product are:

1. Acetic acid (used as such or derived from vinegar). The level of acetic acid is the single most important factor in determining microbiological safety and quality in sauces and pickles (see section 14.4.2). Its efficacy as a preservative agent, measured by the percentage of undissociated acetic acid, is affected by the pH of the aqueous phase and its own dissociation constant. Acetic acid has the characteristic that at the pH of many sauces and pickles it is mainly in the undissociated form, thereby exerting maximum anti-microbial effect. Moreover, the fact that acetic acid has a very low oil:water partition coefficient (compared with sorbic and benzoic acid) means that to all intents and purposes, all its preservative effect is retained in the aqueous phase of an emulsified sauce (for further discussion see Chapter 6).
2. pH of the aqueous phase. Figure 14.1 gives the approximate pH growth ranges for some microorganisms important in food spoilage. As in other foods, *Clostridium botulinum* is unable to grow in a sauce or pickle with a pH value below 4.5
3. Salt and sugar content. Too high a salt content (e.g. >3–4%) is unacceptable from a sensory point of view. Beyond a certain point, sugar

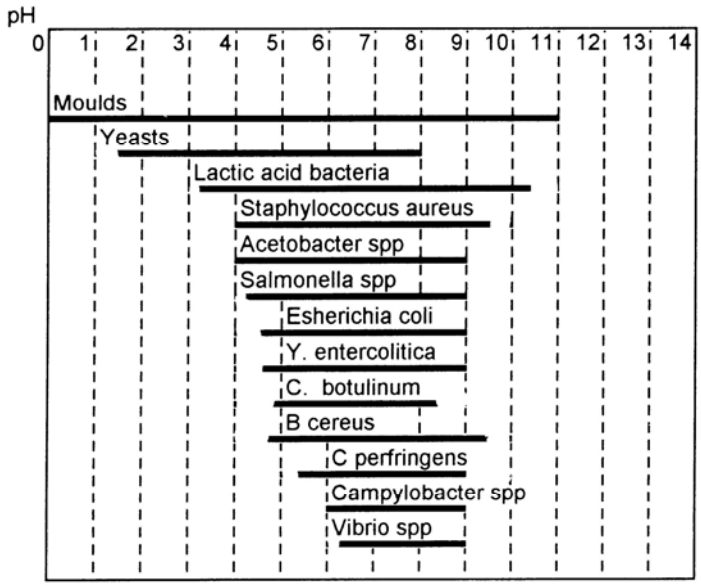


Figure 14.1 Approximate pH growth ranges for some microorganisms important in food spoilage.

and salt most certainly contribute some preservative effect (e.g. through the reduction of water activity as the total solids increase) and their contribution is indeed included in the CIMSCEE formulae (see section 14.4.2).

4. The presence of preservatives (either naturally present or added). Isothiocyanates in horseradish and the volatile 'oil of mustard' (allyl isothiocyanate) in black mustard are good examples of naturally occurring preservative agents that more or less make these materials self-preserving. An example of added (permitted) preservative is potassium sorbate (e.g. in some tomato sauce and cranberry sauce), and where they are used, acidulants such as citric acid, lactic acid and tartaric acid may also play a minor preservative role.

The synergistic effect of acetic acid, pH, salt and sugar on the microbiological safety and stability of mayonnaise and similar products has been studied and defined empirically by a mathematical model which will be discussed more fully in the next section of this chapter.

Composition and formulation are also crucial to the physical stability, and hence consumer acceptability and shelf life of emulsified as well as non-emulsified sauces. In mayonnaise and salad dressings, the egg protein plays a vital role in the stability of the oil-in-water emulsion. The tran-

sient stability of the emulsion depends on factors like the efficiency of the mechanical emulsification, the size distribution of the oil droplets, the intrinsic viscosity of the mix and so on. The long-term stability of the emulsion however depends also on the use of suitable emulsifiers and stabilisers. The egg protein remains the effective emulsifier (surfactant) and stabilisers such as guar gum and xanthan gum are commonly employed to ensure the long-term stability of the product. In some non-emulsified sauces, modified starch is often used to give a texture and to confer the long-term stability of the product. In addition to selecting the right starch (one that can withstand low pH, high shear, heat treatment and one that is less likely to retrogradate and 'weep'), correct processing is important to ensure that the texture benefits of the starch are realised (Figure 14.2).

	Under-cook	Optimal cook	Over-cook
Appearance	Cloudy	Clear	Clear
Texture	Thin, starchy taste	Heavy bodied short textured	Cohesive, long textured
Stability	Poor	Good	Fair
Viscosity	Low	Good	Viscosity drop

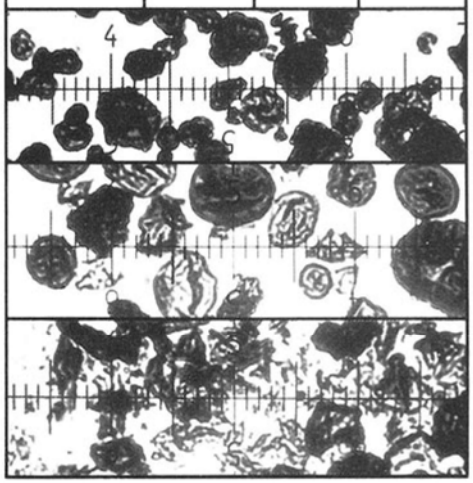


Figure 14.2 Characteristics of under-cooked, optimal, and over-cooked starch slurries. (Source: Food Starch Technology. National Starch & Chemical.)

14.3.3 Availability of oxygen

For long shelf life products such as sauces and pickles, oxygen can be an important factor that affects shelf life. In emulsified sauces, the choice of vegetable oils can have a major influence on the development of oxidative rancidity. Table 14.1 lists the iodine values of some common edible vegetable oils. As can be seen from this table, the more stable oils include rapeseed oil and soya oil, which is one reason why these two oils tend to be the most used in the sauces industry. Sunflower oil has been marketed as being beneficial to health, and whilst it is not in the remit of this chapter to discuss the nutritive aspects of various oils, its use has been seen as desirable, but its greater susceptibility to rancidity development limits the shelf life of products containing it.

Vegetables and fruit used in the manufacture of sauces and pickles often contain enzymes that have not been inactivated. In the presence of oxygen, grated fresh horseradish will brown very quickly due to its polyphenols content. Fresh horseradish should be handled and processed with the minimum of delay and sulphur dioxide (as an anti-oxidant) may also be used to control browning if the shelf life of the end product is not to be reduced.

Table 14.1 Iodine values of vegetable oils – an indication of their susceptibility to oxidative rancidity

Vegetable oil	Iodine value
Rapeseed oil	97–107
Soya oil	125–136
Sunflowerseed oil	125–140
Corn (maize) oil	110–128
Olive oil	80–88

14.3.4 Processing

It is possible to produce microbiologically stable sauces and pickles based on a cold process provided certain criteria are satisfied (see section 14.4.2). Indeed for emulsified sauces, it is neither necessary nor desirable to use a hot process. In recent years, however, consumer demand for milder products has meant that a pasteurisation stage (or alternatively hot-filling not less than 80°C in some cases) is included to achieve an acceptable shelf life for many pickles and some sauces.

Pasteurisation of pickles involves the controlled and limited thermal processing of the final product within its container. Pasteurisation has

three possible advantageous effects in respect of product shelf life, namely (Broomfield, 1993):

1. Thermal destruction of spoilage microorganisms, permitting a lower acetic acid content to be used.
2. Total or partial thermal inactivation of enzymes of vegetable or of microbial origin, thus preventing deteriorative changes caused by enzymes.
3. In the case where self-venting closures are used, removal of air during pasteurising and retention of headspace vacuum on cooling, thus minimising oxygen-dependent and oxidative changes (e.g. darkening and softening).

Hygienic design and practices are the cornerstones of Good Manufacturing Practice and they are fundamental to sauces and pickles manufacture as they are to other food products, irrespective of whether the sauce or pickle is pasteurised or not.

14.3.5 Packaging

The traditional packaging material used for sauces and pickles is glass which provides practically a perfect gas as well as water vapour barrier. In addition, where necessary, hot-filling is possible with glass containers, which can be a useful alternative to in-container pasteurisation. Recent developments in packaging materials, in particular plastics materials, have led to the introduction of the multilayer 'squeezable' bottles for sauces. A typical structure for this type of bottle is: inside PP/adhesive/EVOH/adhesive/outside PP, EVOH being the gas barrier layer and PP the water vapour barrier layer. While this type of container offers the consumer convenience in use, it is not commonly filled hot although it can withstand hot-filling up to 70°C. Moreover, because of its multilayer structure, barrier properties of the container depend on EVOH and PP being present throughout the container. The oxygen barrier property of EVOH is affected by the relative humidity of the environment and this has to be taken into account when designing storage trials for products packaged in this container. Finally, both the packaging supplier and the sauce manufacturer have a responsibility to ensure, particularly for any new sauce/bottle combinations, that the legislative standards in respect of food packaging migration are complied with, and in the UK, as detailed in the Plastics Materials and Articles in Contact with Food Regulations 1992.

14.3.6 Consumer use

Consumer use of multi-use products like sauces and pickles has always been an uncertain factor in respect of product shelf life. Although it is

generally believed that many mayonnaises and dressings are sensitive only to typical acetic acid resistant organisms which are not widespread in the consumer's home, it is important that the possibility of spoilage during use should be considered during the development of mild formulations. Spoilage may be controlled to a certain extent by limiting the shelf life of opened product at room temperature and/or recommending refrigerated storage once the product has been opened. In fact yeast contamination has been known to cause some tomato sauce to ferment and the pack to explode; the use of precise label instructions is very important for microbiologically vulnerable products.

14.4 Challenge testing and the use of mathematical models

14.4.1 Challenge testing

To establish the microbiological safety and stability of sauces and pickles, challenge testing may be used. Challenge testing is a technique which yields information to the manufacturer as to the microbiological status of a product during its 'normal' or expected life before consumption. To the food microbiologist it is the most direct evidence of product safety and stability (Shapton and Shapton, 1991). In practice, challenge testing comprises the direct inoculation of a food with microorganisms. When carried out for safety purposes, the microorganisms will be pathogens which are likely to be associated with the product being tested. For the purpose of stability testing, those spoilage organisms are selected which are known to cause problems in the particular type of food under investigation. The choice of microorganisms for inoculation, their culture and method of inoculation are therefore important considerations for challenge testing. The organisms chosen also require to be 'trained' to be able to survive under adverse conditions (e.g. the presence of acetic acid, low pH, high sugar and so on). Ideally, organisms likely to be used should be cultured from within the sauce plant, however, certain indicator organisms have been identified and specified in the 'code for the production of microbiologically safe and stable emulsified and non-emulsified sauces containing acetic acid' produced by the Comité des Industries des Mayonnaises et Sauces Condimentaires de la Communauté Economique Européenne (CIMSCEE, 1991). This code states that an intrinsically stable sauce is one where acetic acid tolerant organisms will not grow. Of the organisms identified, the mould *Moniliella acetoabutans* is considered the organism most resistant to acetic acid, but is easily eliminated by satisfactory hygiene and/or pasteurisation. Contamination due to this mould within the food industry is considered rare. This organism may be a useful reference, but as it is easily eliminated, it is not usually used in challenge testing.

The CIMSCEE code recommends a twofold examination, covering both safety and stability. Product safety requires that pathogens cannot survive in the sauce, the major hazard being due to salmonellae. However because of the risk of possible contamination where the laboratory is based at a factory, challenge testing is not carried out using *Salmonella* spp. but an indicator organism is used which has been shown to be killed in a similar manner to salmonellae, this being a strain of *Escherichia coli* (NCTC 5933 or VBEEs 01-03). Product stability on the other hand requires that the sauce does not support the growth of spoilage organisms. Several organisms considered to be indicators of resistance to the conditions likely to be present in sauces are (CIMSCEE, 1991):

Moulds: *Monascus ruber* (Van Tieghem), (VMEuMO 01-02) resistant to 1.8% acetic acid;
Penicillium roqueforti (VMMoPe 16-07) resistant to 1.2% acetic acid;
Penicillium verrucosum (VMMoPe 20-07) resistant to 1.2% acetic acid.

Yeasts: *Pichia membranaefaciens* (Hansen) (VYAPi 01-02 and 01-04) resistant to 2.5% acetic acid;
Zygosaccharomyces bailii (VYASa 07-01 and 07-05) resistant to 3.0% acetic acid.

Lactobacilli: *Lactobacillus buchneri* (VBLLa 18-01) resistant to 2.5% to 3.0% acetic acid.

The organisms must be adapted gradually to acetic acid before use, as detailed in the code, or as described originally by Tuynenburg Muys (1971).

Challenge testing, as can be seen, is extremely time-consuming and more importantly requires laboratory skills which may not always be available. Time is a crucial factor in today's product development programmes and as an alternative approach to challenge testing, mathematical models are often used to predict microbiological safety and stability before embarking on a shelf life determination for a new or revised product.

14.4.2 Mathematical models

The CIMSCEE code outlined in section 14.4.1 also includes a model which can be used to establish safety and stability for sauces containing acetic acid derived from vinegar or directly used. This model was developed from research into the Microbiological Composition Analysis (MCA) of edible emulsions carried out by G. Tuynenburg Muys at the Unilever Research Laboratory in the Netherlands in the 1960s. The model takes into account the acetic acid content, its degree of dissociation (this

being dependent on the pH of the food), the salt content, the disaccharide content and the hexose content of the sauce. The contents (percentages) of these ingredients are expressed on the weight of aqueous phase, i.e. water plus acetic acid (or vinegar) plus salt plus sugars. Because the partition coefficient for acetic acid in oil:water systems is very low, for practical purposes it is assumed that all the acetic acid will be available in the aqueous phase. This model which describes the relationship between the above-mentioned ingredients and the potential for microbiological growth has been expressed by the following formulae:

$$15.75\ (1-\alpha)\ (\text{total acetic acid \%}) + 3.08\ (\text{salt \%}) + (\text{hexose \%}) + 0.5\ (\text{disaccharide \%}) + 40\ (4.0 - \text{pH}) = \Sigma_s \qquad (14.1)$$

For any sauce based on acetic acid, if the value of this formula (Σ_s) exceeds 63, safety from microbial pathogens is assured.

$$15.75\ (1-\alpha)\ (\text{total acetic acid \%}) + 3.08\ (\text{salt \%}) + (\text{hexose \%}) + 0.5\ (\text{disaccharide \%}) = \Sigma \qquad (14.2)$$

For any sauce based on acetic acid, if the value of this formula (Σ) exceeds 63, microbial spoilage should not occur.

$(1 - \alpha)$ is the proportion of the total acetic acid which is undissociated and is related to the pH of the sauce and the pK_a of acetic acid.

The model has certain limitations, for example, it does not take into account the effects of any other anti-microbial ingredients, such as preservatives, or any anti-microbial agents naturally present in the foods (e.g. as in horseradish and mustard). Also care must be exercised when particulates are present, as no allowance is made for slow acid equilibration in sauces such as sauce tartare. Furthermore the code does not apply to pickles or dressed salads, and on the whole it badly needs updating.

The inclusion of preservatives can improve the preservation of the sauce, thus allowing an apparently low stability value which might otherwise suggest instability when interpreted on its own. Work by Dakin (Dakin, 1968) suggests that an 800 mg/kg level of sorbic acid in a pickle or sauce has the equivalent effect of 1.0% acetic acid. Care however should be taken in the use of this finding as the partition coefficient for sorbic acid is such that the preservative will be distributed throughout a sauce which has an oil phase, and not be restricted to the aqueous phase of the sauce. This will result in a significantly reduced level of sorbic acid in the aqueous phase of an emulsion, especially in high oil systems, making the preservative action somewhat less effective than would otherwise be expected.

Another empirical model that can be used to predict the stability of unpasteurised pickles and sauces is the 'Preservation Index' put forward by Dakin (Binstead *et al.*, 1971). This model or rule basically states that

Table 14.2 A comparison of CIMSCEE values against Preservation Index values for various sauces

Sauce	Intrinsic safety	Stability	Preservation Index
Mayonnaise	75.7	75.7	4.6
Sweet and sour	66.9	66.5	4.5
Sauce tartare	89.7	57.7	3.3
1000 Island dressing	66.7	66.7	3.7
Ranch dressing*	66.4	52.2	2.9
Hot horseradish	76.5	56.5	3.6

CIMSCEE code has the value 63 as the cut off point. Preservation Index has the value of 3.6 as the cut off value.
*Preserved with potassium sorbate.

the minimum acetic acid content necessary to achieve the satisfactory preservation of all pickles and sauces is 3.6%, calculated as a percentage of the volatile constituents of the product. Thus,

$$\text{Preservation index} = \frac{\text{Total acetic acid acidity} \times 100}{(100 - \text{total solids})} \qquad (14.3)$$

Like the CIMSCEE formulae, the Preservation Index has to be interpreted carefully since an Index lower than 3.6% does not always mean instability, as in the case of mango chutney. A comparison of the stability values of some sauces based on the CIMSCEE formulae and their corresponding values of Preservation Index is given in Table 14.2.

14.5 Shelf life evaluation

The shelf life of sauces and pickles is somewhat difficult to establish predictively, or by accelerated methods. Other than the microbiological mathematical models previously described, there is no known model that can be applied to the more modern varieties of sauces and pickles. In products such as sauces and pickles, composition and formulation play a cardinal role in determining the shelf life of the product and interactions between ingredients can prove very difficult to model. Accelerated tests, for example, may speed up some changes, but others may proceed at the same rate. Since accelerated tests are usually taken to mean storage at elevated temperatures, with or without cycling, they almost always tend to select for a different microflora which would not be representative of what may be present under ambient conditions. Other factors too will be of major relevance in sauces and pickles. Factors such as availability of

oxygen, susceptibility to oxygen and to light, barrier properties of the packaging used and so on may all play a part and contribute to limit the usefulness of any predictive or accelerated methods.

Fortunately, the product group of sauces and pickles is still largely a traditional one, and consequently useful information regarding shelf life is available in the literature as well as within the manufacturing companies. Similar products are often available with which to compare for an estimation of shelf life. Such comparisons must, however, be treated with caution, as subtle changes in formulation and/or packaging format could have a major effect on the shelf life of the product.

Frequently, initial shelf life estimations may be based upon knowledge of the deterioration associated with individual ingredients. For example, in helping to decide the best oil to use in the formulation of an oil-in-water emulsion from a quality standpoint, the resistance of a vegetable oil to rancidity development can be assessed using a FIRA-Astell or Rancimat apparatus (Rossell, 1989). Similarly, the knowledge that a formulation contains materials that are prone to browning will prompt the product developer to pay particular attention to probable colour changes during shelf life determination.

Once the critical factors have been identified, storage trials will be possible with tests designed to detect the potential deteriorative changes that are likely to limit the product life. It must be said therefore, there is yet no substitute for the direct approach to shelf life determination whereby the sauce or pickle being studied is stored under defined and controlled conditions for the whole of the expected shelf life of the product in order that the correct life can be assigned.

14.5.1 Shelf life determination

The first stage in a shelf life determination must be the assessment of microbiological safety. Fortunately, past experience and historical data coupled with the use of HACCP and the CIMSCEE code have meant that microbiological safety can be quickly established for sauces and pickles. A product failing to satisfy the CIMSCEE's criteria for safety and stability for instance, will require further investigation (e.g. challenge testing), or else alternative methods of preservation (e.g. pasteurisation) may be necessary.

Once microbiological safety (and stability) has been established, storage trials can be carried out. From past experience, it can be said that most quality deteriorations tend to manifest themselves as sensory changes so that shelf life tests are usually selected to monitor them. Different conditions of storage may be used and the following are the more common conditions:

chill	0–4°C
ambient (UK)	15–25°C
	(temperate: 25°C, 75%RH)
accelerated	30–37°C
	(tropical: 37°C, 95%RH)

Temperature cycling (important for studying emulsion stability and/or effects of temperature abuse) may be superimposed on these conditions, depending on the purpose of the trial. Other variations in conditions may also be included such as storage in the dark or under artificial light, with or without cycling, and different packaging.

For sauces and pickles, sampling for analysis is normally carried out on a monthly basis, and where appropriate, samples stored under different conditions are compared. The following are examples of the more common tests that are carried out for shelf life determination of sauces:

- Sensory analysis: aroma, flavour, colour, texture, mouthfeel, visual appearance (signs of separation and apparent viscosity and consistency).
- Chemical analysis: pH, total volatile acidity, peroxide value and free fatty acid content of extracted oil, specific components such as the volatile and pungent isothiocyanates in horseradish.
- Instrumental analysis: viscosity measurement using a Brookfield viscometer or Boswick consistometer and colour measurement using a Minolta Chroma Meter (based on the L*a*b* colour notation system).

These tests can be used to give some indication of the rate of change, and help to locate the end-point of the shelf life. The aim of any shelf life determination is to find the level of change in respect of each critical quality attribute beyond which the product is regarded as unacceptable. Some products will start to change from day one. A horseradish product, for example, will begin to brown, and lose its pungency (or 'heat') immediately after packing. Shelf life studies must inevitably include a degree of judgement regarding the level(s) at which the deteriorative changes have become unacceptable. Such decisions are usually made jointly by the technical, sales and marketing (including the customer where appropriate) departments.

14.5.2 A worked example

An example to show the process of shelf life determination is given in this section. The product chosen is an own-label horseradish sauce product, with its compositional standards shown in Table 14.3. The initial study

Table 14.3 Composition of 'hot horseradish sauce' and CIMSCEE calculation of safety and stability values using a spreadsheet program

Ingredient	% Recipe components	% Water phase
Acetic acid 80%	2.6	3.2
Hexose	0.0	0.0
Sucrose	4.6	5.7
Salt	1.6	2.0
Water (pH 3.5)	71.4	89.0
Dissociation constant	0.948	
Microbiological stability	57.4	
Intrinsic safety	77.4	
Preservation index	3.6	
pH	3.5	

included an assessment of microbiological safety and stability of the concept product. As can be seen, the preservation values indicate the product is microbiologically safe, but that its microbiological stability is in doubt (Table 14.3). These results, produced using a popular spreadsheet program, prompted a challenge test on the product. It was believed that the product should be stable, as certain natural constituents in horseradish are bactericidal (i.e. the isothiocyanates). This was confirmed by the challenge testing, results of which are shown in Table 14.4. A comparison with existing products also suggested that the product would remain in an acceptable condition for at least 10 months, but after that, loss in 'heat' and browning could reach unacceptable levels. Storage trials were then carried out to confirm this. Important quality attributes were identified as colour, 'heat' intensity, flavour and viscosity. These parameters were examined over a period of time, by sensory as well as appropriate chemical analyses. Results of these tests are shown in Table 14.5. These results indicate that the product would remain acceptable for a period of about 11 months, and consequently a 10 months life was recommended, which satisfied the customer's requirements and gave a good margin of safety of about a month.

Similar methods of determination can be applied to most, if not all of the ambient-stable sauces and pickles. The value of a mathematical model (e.g. the CIMSCEE model) as a first step in the development process is that it gives the development personnel an opportunity to fine tune the formulation before going to a full shelf life determination. The model also enables decisions to be made early in the product development programme as to whether or not a pasteurisation stage is required as part of the manufacturing process.

Table 14.4 Results of the challenge testing on hot horseradish sauce

Time	Media	Control	*Lactobacillus buchneri*	*Zygosacch-aromyces bailii* 07-01	*Zygosacch-aromyces bailii* 07-05	*Pichia membranae faciens* 01-02	*Pichia membranae faciens* 01-04	*Penicillium roqueforti*	*Penicillium verrucosum*	*Monascus ruber*
24 hours	L agar	400	400	20	40	70	50	70	50	30
	L agar +1% acetic acid	<10	<10	<10	<10	<10	<10	<10	<10	<10
8 days	L agar	200	<10	<10	<10	<10	30	20	<10	<10
	L agar +1% acetic acid	<10	<10	<10	<10	<10	<10	<10	<10	<10
22 days	MRS	200	60	<10	<10	<10	<10	<10	<10	140
	MEA	<10	<10	<10	<10	<10	<10	<10	<10	<10
	MRS + acetic acid 1%	<10	<10	<10	<10	<10	<10	<10	<10	<10
	MEA + acetic acid 1%	<10	<10	<10	<10	<10	<10	<10	<10	<10
32 days	MRS	150	<10							
	MEA	20	<10							
	T.V.C.	400								

Table 14.5 Changes in mustard oil content (as allyl isothiocyanate) and assessor's perceived 'heat' of hot horseradish sauce over a 12 months' period

Product age	Mustard oil content (%)	Perceived heat*
1 month	0.81	10
2 months	0.77	9
3 months	0.74	7
4 months	0.72	7
5 months	0.74	6
6 months	0.76	6
7 months	0.74	5
8 months	0.73	4
9 months	0.73	5
10 months	0.69	4
11 months	0.69	2

*The sensory heat level is judged on a subjective 1 to 10 scale. 10 is hot, 1 lacks heat.

14.6 Current developments

14.6.1 Alternative ingredients and packaging

Within the sauces sector, over the past few years there have been major moves to development of reduced fat, and even fat-free products (the so-called 'lite' products) as well as the use of alternative packaging formats. For example, products are being developed using various fat mimetics and replacers, based upon a number of raw materials. These are claimed by the suppliers to produce an acceptable product from a sensory point of view. Often, however, the system being sold does not completely provide all the characteristics associated with vegetable oils, when used in a sauce or salad dressing. Developers are therefore working on combining several of these systems in order to evaluate any possible synergistic effects, with a view to reproducing the quality characteristics of the product with a traditional oil content. Similarly, pickles containing less acid and/or sugar, albeit pasteurised, are becoming more popular as a result of consumer demand for milder products. Gas packaging (e.g. vacuum packing) in conjunction with plastics materials (Kilcast, 1984) has also been used to package pickles (e.g. sliced beetroot) for chill distribution, giving the products a novel and 'fresher' image. These developments have major ramifications for product shelf life. Some of the systems being used have been available for many years, but their effects in a sauce or pickle system are not well documented. Others are novel in their applications, and their effects under certain conditions are not known. Combining these systems

(ingredients and packaging) to effect a synergistic outcome, with a view to producing a product of the required sensory characteristics and pack appeal, may result in some beneficial effects being realised initially, which cannot be sustained during the whole of the product shelf life. Consequently the product developer will need to consider carefully all aspects of potential product deterioration, without the luxury previously afforded to him of comparing with any existing products.

Differing process requirements (e.g. as a result of using emerging process technologies) also add to the complexity in developing new products and establishing their shelf lives. Well planned and conducted shelf life determinations involving relevant and meaningful physical, chemical, microbiological and sensory analyses must be carried out over time with these new products, to unequivocally establish their safety and acceptability.

14.6.2 New techniques in shelf life determinations

Whilst at the time of writing there are few novel approaches to shelf life determination of sauces and pickles, much research has been done and is still being carried out into the extension of mathematical modelling in food products in general (e.g. the UK's MAFF Micromodel). These models may, in the future, be more widely used by the food technologist in establishing the 'safe' life of sauces and pickles. These models, coupled with other intelligent knowledge-based (computer) systems being developed (see Chapter 3) will enable product development personnel to predict shelf life early in the development programme.

14.7 Conclusion

Sauces and pickles traditionally have relied on a combination of acetic acid, salt and sugar for their preservation. In more recent times, the use of thermal processing (pasteurisation), preservatives (e.g. sorbic acid) and other functional ingredients have enabled the food technologist to vary the composition of these products resulting in less salty and less acidic products, which are increasingly being demanded by the consumer. Even more recently the introduction of fat replacement systems has additionally offered the opportunity for further new product development for sauces. For the food technologist, the determination of shelf life has moved from simple monitoring of well known deterioration processes of the basic ingredients to more complicated investigations, concentrating not only on ingredient changes due to ageing, but also on the potential for microbiological changes as well as possible physico-chemical changes under many different conditions.

Some of the challenges for the food technologist have been highlighted in this chapter, and examples of probable degradation have been given. To be successful in this product group, the product developer must know the hazards and risks associated with the materials he is using, and be alert to any possible risks associated with changes in the product matrix brought about by the use of new formulations, novel ingredients and modern packaging formats.

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15 Frozen foods

H. SYMONS

15.1 How many industries?

As their name implies all frozen foods depend for their stability and hence an adequate shelf life on product temperature being maintained colder than the freezing point. For most foods the freezing point is around –2°C (28.4°F). This superchill temperature is totally unsatisfactory for holding any frozen products, all of which demand far colder temperatures. This has led to prefixes being used in front of the adjective 'frozen' (such as 'quick' or 'deep') to make the point that merely being hard because it is cold is an inadequate safeguard for maintaining the quality of frozen foods.

15.1.1 Speed of freezing

The term 'quick' was introduced by Clarence Birdseye, the father of the retail frozen food industry. Birdseye had at least two reasons to select the adjective 'quick'. One was to distinguish the new industry he was struggling to develop, based on superior quality presented to the retail consumer, both from the frozen meat trade (which had adopted –10°C (14°F) as its storage temperature) and also from the 'sharp' frozen industry in which the product to be frozen is placed in a chamber called the 'freezer' at –7 to –10°C (19.4°F to 14°F) with no effort to separate already frozen product from ambient product introduced to be frozen in the same chamber. Not only is 'sharp' freezing very slow, taking days or even weeks rather than hours, but also the product may suffer frequent large temperature fluctuations as new batches of product at ambient temperature are introduced into the chamber for freezing. Much of the frozen meat in international trade is carried today in container ships at –18°C (0°F) on account of the impracticability of providing different temperatures for various parts of the cargo. Enormous quantities of fish, fruits, vegetables and shrimps are now also traded internationally and these products all demand frozen food temperatures.

Birdseye's second reason for calling the new industry 'quick frozen' was to promote his recent invention, the multi-plate froster, which freezes product in a controlled and rapid fashion. Jul (1984) relates a discussion

he had, in the late 1930s, with executives in Birds Eye Division of General Foods in the USA, who had purchased Birdseye's patents, when he was able to obtain their admission that the speed of freezing was not as important to product quality as the maintenance of adequately cold temperatures (–18°C (0°F)) or colder during distribution.

Speed of freezing plays a part in determining shelf life. The first recognition of the importance of speed in freezing was probably due to experiments by Plank *et al.* (1916) who demonstrated superior product quality when the Ottesen method of freezing (patented in 1911) was employed and the product quality compared to 'sharp' frozen material. The 'Ottesen' method relies on intimate contact with the material to be frozen – generally fish – with cold sprays of isotonic sodium chloride. The Ottesen method was abandoned either because of the difficulty of maintaining the isotonicity of the sodium chloride solution or because, when the solution was not precisely isotonic, some salt would be picked up by the product leading to early onset of rancidity.

Rather than coin the adjective 'quick' it would have been more accurate if the experimenters had stressed the need for freezing to be carried out in a controlled fashion in a device designed to freeze product, entirely separate from any storage facility. Undue emphasis on the importance of freezing speed is misleading. Speed of freezing within the range normally encountered in practice has little, if any, effect on quality. Excessive freezing speeds can ruin product. An increase in volume of around 10% is associated with freezing most foods. The build up of internal pressure during very rapid freezing (such as obtained when product is immersed in total loss refrigerants such as liquid nitrogen or carbon dioxide), shatters the already frozen, and now supercooled and therefore brittle, external layers. Providing the speed is not excessively slow, days or weeks rather than hours, most products are comparatively insensitive to the speed of freezing. Broadly speaking faster is marginally better than slower in most products. This is particularly true for fruit and vegetable products, less so for animal tissue. Most of the advantages apparent immediately post freezing in plant tissue are however lost during subsequent storage, distribution and thawing. Current practice in the industry freezes product quickly but this reflects more the need economically to process a large quantity of product in as small a factory space as practicable rather than any obeisance to the demands of product quality.

The Codex Alimentarius Code of International Practice for Processing and Handling of Quick Frozen Foods requires freezing to be carried out in equipment designed to freeze product and at a speed appropriate to the product. Thawing is not the reverse of freezing, unless microwave thawing is used. It is far slower than freezing and is generally carried out by the consumer in an uncontrolled fashion.

15.1.2 Ice cream/quick frozen foods/frozen foods

If the frozen meat trade is defined as employing –10°C (14°F) as its characterising storage temperature two other frozen food industries can also be defined. The ice cream industry requires temperatures as cold as –20°C (–4°F) while the 'quick/deep frozen food' industry (colloquially referred to as 'frozen foods') demands –18°C (0°F).

A distinction between 'quick frozen' and 'frozen' retail products is preserved in several European countries. 'Surgelé' contrasts with 'Congelé' products in France; 'Tiefgefroren' contrasts with 'Gefroren' in Germany, and 'Surgelato' with 'Congelato' in Italy.

The choice of zero Fahrenheit, which translates into –17.8° on the Celsius scale, for quick frozen foods does not imply any magical properties for this temperature. Clarence Birdseye was an American who thought in Fahrenheit and advocated zero to minus five as an appropriate temperature, with the minimum of fluctuations, at which to hold and distribute quick frozen foods (Birdseye and Fitzgerald, 1932). In the 1950s a massive research programme into frozen food quality was undertaken by the Western Regional Research Laboratory of USDA/ARS in Albany, California. The results of this research (Van Arsdel *et al.*, 1969), determined the answer to the question 'what happens, in microbiological, nutritional and sensory terms to the various products being frozen by the industry at different sub-freezing temperatures?' One outcome of this research was the reaffirmation of zero (forgetting the –5 advocated by Birdseye), as the industry norm by Harold Humphrey, then the General Manager of Birdseye Division of General Foods (Olson, personal communication). The concept of Time–Temperature Tolerance (TTT) to describe frozen food stability was developed by this programme.

15.2 Stability of frozen foods

15.2.1 Microorganisms

Microbiological growth overwhelms physico-chemical changes at around –8°C (18°F) or warmer temperatures. Michener and Elliott (in Van Arsdel *et al.*, 1969) list the maximum recommended storage temperatures at which microbiological spoilage ceases. Most authorities put this at between –9°C (16°F) and –12°C (10°F). The discrepancies in the minimum temperatures found can probably be ascribed to the short length of some of the experiments. Moulds can take months rather than weeks to develop substantially. Although microbiological spoilage can be discounted at frozen food storage temperatures it must be borne in mind that the enzymes in any microorganisms present in the product will still

play a part in spoilage. Hence the point that a product produced under hygienic conditions or heat processed (blanched or cooked) will enjoy a longer shelf life than its unhygienic or raw counterpart. Many common pathogens (notably salmonellae, vegetative cells of *Clostridium perfringens* and *E. coli*) decline in numbers by several logs during prolonged cold storage but this must never be regarded as a substitute for good hygiene in processing.

15.2.2 Ice mobility

Ice, an inevitable concomitant of attaining temperatures as cold as –18°C in food systems, is restless, always responding to any vapour pressure differential created by any thermal gradient, which is the reason for demanding reasonably constant temperatures during distribution of frozen foods. Fluctuations in product temperature of 2–3°C, as are likely to be found in bulk cold stores maintaining –18°C (0°F) or colder, are unlikely to cause perceptible damage even over long periods. On the other hand frequent fluctuations in temperature, particularly large fluctuations at 'warm' temperatures (i.e. close to or in the zone of maximum crystal formation – between –1°C (30°F) and –5°C (23°F)), which can be experienced in retail display cabinets and during the 'carry home' period, cause ice crystals to ripen or grow, coalesce and move to the product surface or, if space allows, onto the inside of the packaging material. This leads ultimately to a freeze-dried product if the packaging is permeable to moisture allowing the sublimed or evaporated water vapour to escape. The loss of moisture results in toughening of animal tissue and greater exposure to any oxygen present.

Oxygen is the bugbear of almost all frozen foods, leading to oxidative rancidity if any unsaturated lipids are present, loss of colour and development of off-flavours. Moisture loss by sublimation from the surface of products leads to 'freezer burn', an unsightly, white colour which can be mistaken for mould but which is resolved on rehydration during cooking unless it is severe. A whitish surface appearance, sought after in some markets, can also be induced, in products such as poultry, by very rapid surface freezing (by liquid nitrogen or carbon dioxide), which produces very small crystals leading to scattering of incident light.

15.2.3 Physico-chemical reactions

The most important quality changes during frozen storage which determine shelf life encompass colour loss and colour change in vegetables. In green vegetables this is due to hydrolysis of chlorophyll to pheophytin, giving a dull khaki colour. Examples of the principal reactions occurring during storage are flavour loss, followed by the development of off-

flavours; vitamin loss; retrogradation of starch; protein denaturation; hydrolytic (in milk) and oxidative rancidity; drip formation in animal tissues; crystallisation of sucrose (on the surface this gives rise to spectacular volcanic excrescences of sucrose hydrate, the formation of which proceeds fastest at –23°C (–10°F)) and crystallisation of lactose (in ice cream this causes a grainy texture). Good accounts of these changes in the various product categories can be found in Jul (1984), Van Arsdel *et al.* (1969), and Mallet (1992).

Nucleation, crystal ripening, changes on thawing and associated quality defects peculiar to frozen products (Fennema, 1991; Bald, 1991; Jul, 1984; Van Arsdel *et al.*, 1969; Reid, in Mallet, 1992) are all important considerations in assessing shelf life and can affect formulation considerations in selecting ingredients and processes which minimise these induced changes.

15.2.4 Time–temperature tolerance (TTT)

The time–temperature tolerance concept, developed as a result of the massive programme of research into frozen food stability at Albany, postulated that quality loss in frozen foods is proportional to the reciprocal of the storage temperature. This programme was concerned with evaluating the quality stability of frozen products then being marketed in the US and paid relatively little attention to the suitability of different vegetable varieties for freezing, growing conditions, processing or packaging but concentrated on evaluating product stability taking for granted the current industry practices.

A survey of frozen food quality conducted in 1983/4 (Earl *et al.*, 1985) found frozen products in the distribution system as old as 840 days! Arrhenius plots on the assumption that quality loss is a zero order reaction fitted the data best. The reaction order of quality loss can in fact lie between zero and two but the data fitted best to zero order kinetics.

15.2.5 Product quality, processing and packaging (PPP) factors

Jul (1984) drew attention to the very profound effects that the level of intrinsic product quality (freshness, suitability of variety for freezing and so on), the processing (whether blanched or cooked, whole, sliced or comminuted, addition of antioxidants, etc.) and the packaging (presence of glaze, breading, batter or gravy, oxygen and moisture permeability of primary packaging, how close fitting to the contours of the product, whether evacuated or gas-flushed) all exert on the final product quality. These can overwhelm TTT considerations in determining shelf life. Figure 15.1 illustrates the values for shelf life at different temperatures for various frozen products, including the effects of different packaging on bacon.

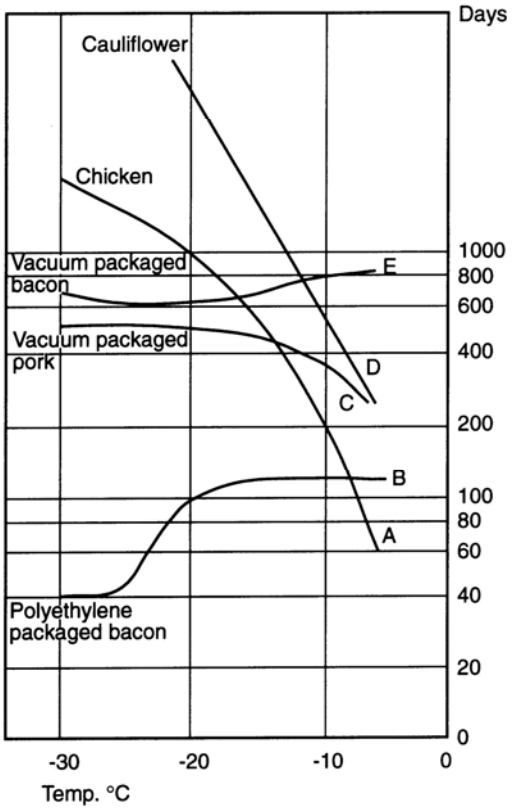


Figure 15.1 Estimate shapes of shelf life curves for various frozen foods. (Source: M. Jul, 1984. In: Thermal processing and quality of food, Zeuthen *et al.* (eds), 1984.)

15.2.6 Glassy state

The classic TTT concept, which has long served the frozen food industry well, especially after taking account of the modifications proposed by consideration of the PPP factors, has recently been refined by the recognition of the importance of the glassy state in frozen foods (Reid, in Mallett (1992) and Blond and Colas, in Bald (1991)). As an increasing proportion of water is converted to ice with decreasing temperature the remaining solutes become progressively more concentrated and exceedingly viscous until, in a maximally freeze-concentrated solution, the glass transition temperature ($T_{g'}$) peculiar to the food is reached. At this temperature, the material between the ice crystals becomes a glass: an amorphous metastable solid, but retaining the disordered structure of a liquid, with a high

viscosity ($>10^{13}$ Pa s). This change from a visco-elastic liquid (rubber) to a glass is accompanied by a dramatic decrease in mobility. All reactions slowed down as a consequence and hence quality loss greatly retarded, almost to the point of being suspended over the few years of interest to frozen foods. The $T_{g'}$ of ice cream varies between –23° to –43°C depending on formulation (Goff *et al.*, 1993).

Moisture content has little influence on the $T_{g'}$; the presence of solutes of low molecular weight (such as sugars) lowers the $T_{g'}$; however substances of high molecular weight (such as starches) exert little effect. This has the consequence that increasing maturity in many vegetables (maturity being commonly associated with a decrease in sugars and an increase in starch) will result in raising the $T_{g'}$ as also will increasing blanching time in products such as French fries in which the cut surfaces allow the leaching of sugars. Reid (in Mallet, 1992) further suggests that, at frozen food temperatures warmer than the $T_{g'}$, the rate of quality loss may be dependent on the difference between the storage temperature and $T_{g'}$ rather than with the reciprocal of the storage temperature. Developing knowledge of the glass transition temperatures of materials commonly frozen and the factors which alter these temperatures will enable biotechnologists to manipulate plant genomes to achieve a warmer $T_{g'}$ and product developers to formulate products and adjust processes to give as warm a $T_{g'}$ as feasible. It is clearly advantageous to plan storage temperatures to take account of the $T_{g'}$ of the stored products, remembering that it is a waste of energy and money to store at temperatures colder than the $T_{g'}$ while, in the case of long-term bulk storage, the quality/cost equation is likely to favour attaining temperatures close to the $T_{g'}$.

15.2.7 Know your product

A prerequisite in planning any shelf life determination of a frozen product is to select the most thermo-labile important quality attribute, whether this be flavour loss, colour change, toughening, development of rancidity and so on. If experience is lacking in the likely stabilities of the various quality attributes help can be sought in the literature. A list of anticipated shelf lives for a number of products commonly frozen can be found in the literature, notably in Table 15.1 of practical storage life (PSL) taken from the International Institute of Refrigeration (IIF) (1986) where expected PSLs are tabulated for three temperatures, –12°C (10°F), –18°C (0°F) and –24°C (–12°F). The shelf lives given for –24°C (–12°F) are conservative, none more than 24 months because of a lack of published data since few investigators are concerned with longer storage periods for food products. Guadagni (in Van Arsdel, 1969) found no measurable changes over five years at –29°C (–20°F) in most frozen fruits. Jul (1984) quoting Bengtsson *et al.* (1972) makes the same point. Many meat products probably have a

Table 15.1 Practical storage life (months) at several storage temperatures

Product	−12°C (10°F)	−18°C (0°F)	−24°C (−12°F)
Fruits			
Raspberries/strawberries (raw)	5	24	>24
Raspberries/strawberries in sugar	3	24	>24
Peaches, apricots, cherries (raw)	4	18	>24
Peaches. apricots, cherries in sugar	3	18	>24
Fruit juice concentrate	–	24	>24
Vegetables			
Asparagus (with green spears)	3	12	>24
Beans, green	4	15	>24
Beans, lima	–	18	>24
Broccoli	–	15	24
Brussels sprouts	6	15	>24
Carrots	10	18	>24
Cauliflower	4	12	24
Corn-on-the-cob	–	12	18
Cut corn	4	15	>24
Mushrooms (cultivated)	2	8	>24
Peas, green	6	24	>24
Peppers, red and green	–	6	12
Potatoes, French fried	9	24	>24
Spinach (chopped)	4	18	>24
Onions	–	10	15
Leeks (blanched)	–	18	–
Meats and poultry			
Beef carcass (unpackaged)[a]	8	15	24
Beef steaks/cuts	8	18	24
Ground beef	6	10	15
Veal carcass (unpackaged)[a]	6	12	15
Veal steaks/cuts	6	12	15
Lamb carcass, grass fed (unpackaged)[a]	18	24	>24
Lamb steaks	12	18	24
Pork carcass (unpackaged)[a]	6	10	15
Pork steaks/cuts	6	10	15
Sliced bacon (vacuum packed)	12	12	12
Chicken, whole	9	18	>24
Chicken, parts/cuts	9	18	>24
Turkey, whole	8	15	>24
Ducks, geese, whole	6	12	18
Liver	4	12	18
Seafood			
Fatty fish, glazed	3	5	>9
Lean fish[b]	4	9	>12
Lobster, crab, shrimps in shell (cooked)	4	5	>12
Clams and oysters	4	6	>9
Shrimps (cooked/peeled)	2	5	>9

Table 15.1 *Continued*

Product	−12°C (10°F)	−18°C (0°F)	−24°C (−12°F)
Eggs			
Whole egg magma	–	12	>24
Milk and milk products			
Butter, lactic, unsalted pH 4.7	15	18	20
Butter, lactic, salted pH 4.7	8	12	14
Butter, sweet cream, unsalted pH 6.6	–	>24	>24
Butter, sweet cream, salted (2%) pH 6.6	20	>24	>24
Cream	–	12	15
Ice cream	1	6	24
Bakery and confectionery products			
Cakes (cheese, sponge, chocolate, fruit, etc.)	–	15	24
Breads	–	3	–
Raw dough	–	12	18

[a]Carcass may be wrapped in stockinette.
[b]The PSL for single fillets of lean fish would be 6, 9 and 12 months at −18°C (0°F), −24°C (−12°F) and −30°C (22°F) respectively.

Source: IIR (1986)

shelf life of over 2 years if PPP factors are well managed and the product held at frozen food temperatures. Winger (1984) found no loss in eating quality of grass fed lamb, hygienically processed and well packaged, after two years at −10°C (14°F). Anecdotal evidence tells us that the flesh of mammoths, after several thousand years in the permafrost in Siberia, was still recognisable and edible if not actually delicious! Help in determining what is the most thermo-labile attribute in a new product may be obtained by a judicious assessment of similar competitors' products. If date marking is practised it is a simple matter to search out both 'old' and recent production and assess the changes found. In the absence of date marking, production codes can often be broken since these are seldom cryptic.

Once the decision has been made as to which quality attributes are critical, a taste panel needs to be assembled and trained, selecting those who show reasonable sensitivity to the particular attribute and who can demonstrate consistent scores.

15.2.8 Objective tests

Objective tests are available for a number of quality attributes of frozen foods. These seldom faithfully reflect consumer preferences and are little

used in day-to-day industry testing in the course of shelf life predictions or quality assurance. If a nutritional claim is made, then of course how that nutrient withstands prolonged cold storage and simulated thermal abuse is important. The loss of vitamin C and the ratio of chlorophyll to pheophytin in green vegetables can be a measure of thermal abuse (Olson and Dietrich in Van Arsdel *et al.*, 1969) as can the decrease in optical density of a muscle homogenate in cod (Love, 1962), the development of thiobarbituric acid (TBA) or peroxide value in products containing unsaturated lipids (Dalhoff and Jul, 1965), the development of cold store flavour in fish (McGill *et al.*, 1974) and a host of other indicators in various products. These objective tests may be useful to determine alongside sensory changes and may also be necessary in any claim or litigation alleging unsatisfactory product handling or failure to meet a quality specification by a third party. They have seldom, however, been found to reflect accurately, and with sufficient sensitivity, consumer preferences. In general they only confirm what is already abundantly apparent from taste panel assessments.

15.2.9 Accelerated testing

Seldom can the luxury be permitted of long-term assessment of product quality over the months or years of anticipated shelf life at frozen food temperatures. Some form of accelerated testing is necessary which is likely to result in sacrificing a degree of accuracy in the results obtained. This presupposes that all frozen products lose quality, at warmer temperatures than colder, i.e. possess a positive $Q_{10}(q_{10})$. ($Q_{10}(q_{10})$ is the ratio of quality loss at two temperatures in the range of frozen food temperatures, that are 10° apart: 10°C for Q_{10} and 10°F for q_{10}.) Not all frozen products exhibit a positive $Q_{10}(q_{10})$. Neutral stability, or a $Q_{10}(q_{10})$ of 1, is found in a few products, such as salami, which may be a component in a frozen product. The quality of this cured, fermented and dried product is temperature independent and it enjoys an equally long shelf life at frozen food temperatures as at chill or ambient. A negative Q_{10} is rare and was first described by Boegh-Sorensen (1972) who found reverse stability in frozen vacuum-packaged cured sliced pork products. Shelf life was almost independent of storage temperatures between –6 to –23°C (21 to –9°F) while one product, smoked streaky bacon, exhibited a longer shelf life at the warmest temperature. Lindeloev (1978) showed that at a storage temperature as cold as –25°C (–13°F) the shelf life of bacon is shorter than at –5°C (23°F). This is an example of the effect of concentration of catalysts of oxidative rancidity (sodium chloride, nitrate and nitrite) by the subtraction of ice from the solution overwhelming the effect of temperature reduction. Christensen and Jensen (in Zeuthen *et al.*, 1984) did not find reverse stability in cured fish.

Accelerated testing can usefully be carried out by holding control product at −40°C (−40°F) and exposing test samples to three or four different storage temperatures between −30°C (−22°F) and −10°C (14°F). For many products the reference samples may be held at −30°C (−22°F) since little change occurs in most products at colder temperatures.

15.2.10 Just noticeable difference

The goal of shelf life determination is to estimate the length of time during which the product under test will still be appreciated by the ultimate consumer as being of the level of quality expected for the product, that is to say for how long it will maintain 'practical storage life' (PSL). Loss of quality in frozen foods is a gradual process, the changes being slow or very slow, cumulative and irreversible. PSL is a highly subjective concept and difficult to measure by taste panel procedures. In the rarefied atmosphere of a taste panel, as opposed to a meal situation, the trained assessors are likely to discriminate between nuances of quality unlikely to be appreciated by the consumer. A way out of this difficulty is to measure the time to 'just noticeable difference' (JND) or 'high quality life' (HQL) by a trained taste panel and then multiply this by an arbitrary figure, generally between 2 and 5, to arrive at PSL. In products peculiarly sensitive to colour loss (peaches, cauliflower, red pigmented fish) PSL may be close to JND.

JND is conveniently defined as the moment during storage at the expected temperatures of the cold chain at which a proportion (generally 70%) of the trained assessors can correctly distinguish the product under test from the control (held at −30°C (−22°F) or −40°C) using a triangular or duo–trio test. It can be argued that the proportion of assessors able to discriminate successfully should be much lower, say 25%, on the basis that a small proportion of consumers is likely to be highly discriminatory concerning the particular quality attribute deemed to be critical. Anyone with experience of taste panels knows how very sensitive individuals can be to particular sensory attributes and sometimes surprisingly insensitive to others.

Dalhoff and Jul (1965) preferred a sensory scoring system (−5 equals dislike extremely, 0 neither like nor dislike, +5 like extremely) to determining JND by triangular or duo–trio testing. A decrease of 1 point on the scale would equate to JND. An advantage of this procedure is that fewer replicates are required than the four replicates for each time/temperature stipulated by Guadagni (in Van Arsdel *et al.*, 1969). An objection is that the preference scoring system is likely to be population specific. For instance quality expectations for fish flavour would be very different between a Danish population (who expect their fish to be alive when purchased) and an English population accustomed to fish held in ice