

for several days. The English taste panel would probably score the Danish fish as lacking in fish flavour whereas the Danes would score the English fish as partly rotten at best!

15.2.11 $Q_{10}(q_{10})$

Most frozen products enjoy shelf life measured in many months or even years. During product development answers as to the likely shelf life of a new or modified product are required in weeks or a few months to be of any use. Hence there is the need for accelerated shelf life determinations. Accelerated shelf life tests aim to establish the *rate* of quality loss with temperature change and hence to enable PSL at conventional distribution temperatures to be assessed far more rapidly than the long-term tests at the anticipated storage temperature. This rate can be expressed as the ratio of the shelf lives found at two different temperatures, generally 10°C (Q_{10}) or 10°F (q_{10}) apart. For instance, Guadagni (in Van Arsdel *et al.*, 1969) found stabilities of strawberries, assessing both colour and flavour, held at three different temperatures, -18°C (0°F), -12°C (10°F) and -7°C (20°F) to be 360, 60 and 10 days respectively. The q_{10} is therefore 360/60 or 6 and 60/10 or 6 again for the respective 10°F differences measured. Not all rate determinations work out as neatly as strawberries and it is probably futile to try to fit quality loss determinations to a particular mathematical formula. Foods are complicated biological systems and do not lend themselves to convenient mathematical expressions which can be applied to a wide variety of products.

15.3 Product characteristics

15.3.1 *Fruits and vegetables*

Most fruits freeze well; that is to say the thawed product is barely distinguishable from the raw fruit before freezing. Although strawberries do not fall into this category, losing texture during freezing and thawing, the early days of the frozen food industry saw strawberries dominating the market for frozen fruit. The fruit was mixed with sugar in wooden barrels placed in a frozen food warehouse and rolled periodically to mix the fruit and sugar. The frozen product was used in preserves and ice creams. Heat inactivation of the enzymes that cause rapid discoloration by enzymic browning leads to a cooked flavour which is unacceptable and the addition of syrups with ascorbic acid as an antioxidant is used instead. q_{10} s for frozen fruit, measured on flavour and colour, have been found to range from 2.2 for blueberries to 6.0 for strawberries in dry sugar (Guadagni in Van Arsdel *et al.*, 1969).

Frozen vegetables have enjoyed enormous success in many different parts of the world. Since many vegetables do not can well, the introduction of frozen vegetables has meant populations living in high latitudes can enjoy summer vegetables all year round instead of having to rely largely on root crops in the winter. Properly blanched vegetables have a long shelf life at frozen food temperatures enabling them to be exported all over the world to remedy crop shortfalls and to span the seasons. During storage chlorophyll is converted to pheophytin, with loss of green colour and introduction of a khaki hue, and this can be used as an objective test for quality loss in green vegetables. Vitamin C can also be used as an objective indicator of quality loss. The most sensitive quality attribute is a diminution of flavour accompanied by a loss of colour.

15.3.2 Seafood

Microbiological spoilage is the principal cause of quality loss in seafood at temperatures above chill; around 0°C (32°F) enzymic breakdown of protein becomes the principal cause of quality loss; below -8°C (18°F) microbiological spoilage ceases and protein denaturation coupled with oxidative rancidity in fatty species become the chief factors affecting quality.

Figure 15.2 illustrates the stabilities at various temperatures of several species of commonly consumed finfish. Lane (1984) pointed out that sensory characteristics of frozen fish change in intensity during storage rather than in character. The development of rancid flavours and progressive toughening accompanied by the development of cold store flavour are the principal sensory changes. In the case of young fish (e.g. codling) the initial stages of cold store damage may give rise to an increase in acceptability scores. The 'firming' of the soft texture characteristic of young fish by the early onset of protein denaturation is preferred by most taste panellists (Kelly, 1969). Assessing codling in storage trials may therefore result in an initial rise in preference for texture before the expected decline sets in. Flavour is probably more critical than texture (Connell and Howgate, 1971) since this tends to be lost before protein denaturation is appreciable. Formaldehyde is formed during cold storage by enzymic decomposition of trimethylamine oxide (TMAO). Formaldehyde content is a good objective criterion of time/temperature exposure in frozen gadoid species (Boeri *et al.*, 1993). This formaldehyde reacts with proteins, thereby decreasing their solubility in salt and buffer solutions (Rehbein, 1971). Quality loss during cold storage of fish is characterised by increasing loss of water-holding capacity, decrease in protein extractability and a slight loss in ATPase activity (Reid *et al.*, 1985). Much colder temperatures than -18°C (0°F) are useful for bulk storage of seafood. In Japan the retention of a pristine white colour in surimi

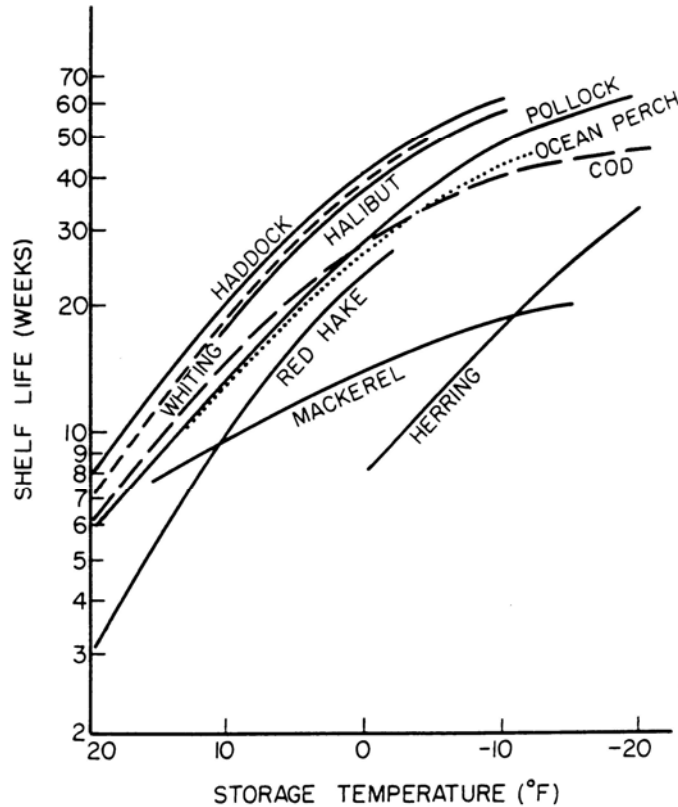


Figure 15.2 Average shelf life values for selected finfish based on literature reported values. (Source: IIR, Proceedings of 'storage lives of chilled and frozen fish and fish products', 1985.)

demands storage temperatures as cold as -60°C (-6°F). Magnussen (1992) reviews the use of such temperatures on mackerel and salmon. Steynor (1992) describes a 2000 tonnes chamber holding -60°C (-6°F) in South Africa.

Of all seafood species, squid (*Loligo duvaucelli*) probably is most sensitive to lack of product freshness leading to reduced stability in subsequent storage. Squids held for two days in ice lose flavour and the cold storage life is dramatically shortened (Jose Joseph *et al.*, 1985).

15.3.3 Meat

Meat, whether it be lamb, venison, beef or poultry all freeze well. Consumer preference is for chilled meat. Some 80% of the chilled beef purchased at supermarkets in the USA is subsequently frozen by the

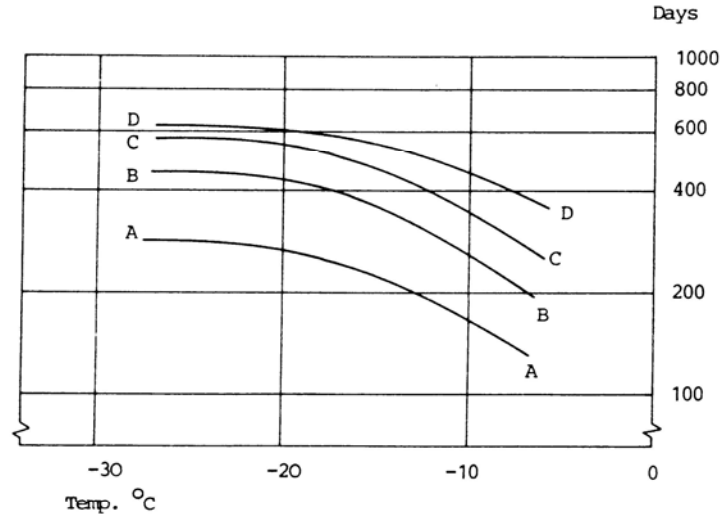


Figure 15.3 Examples of the influence of PPP factors on shelf lives of frozen foods. A. Pig meat with high iodine number in fat; B. Pig meat with low iodine number in fat; C. Same meat as B, but cooked; D. Same as C, but vacuum packaged. (Source: M. Jul, 1984. In: Thermal processing and quality of foods, Zeuthen *et al.* (eds), 1984.)

housewife at home. This reaction against purchasing frozen beef probably reflects a desire on the part of the purchaser to assess quality (ratio of bone to muscle, degree of marbling, presence of excess fat and so on) rather than any prejudice against the frozen beef processor. Stability of frozen meats can be affected by the diet of the animal. Pigs reflect in their depot fat the degree of unsaturation of the fat component of their diet. Figure 15.3 gives examples of the influence of the degree of unsaturated fat on shelf life of pig meat. Grass fed frozen lamb is recognised as having a greater stability in the frozen state than its grain fed counterpart. Rapidly chilled muscles become tough on freezing and thawing, a phenomenon known as 'cold shortening', which scarcely affects poultry. This applies with especial severity to small animals such as lamb, as the sheer bulk of the beef carcass precludes all but superficial muscles from chilling with sufficient rapidity to undergo 'cold shortening'. Electrical stimulation post-slaughter can reduce the time the carcass needs to spend above 10°C (50°F) to avoid 'cold shortening'. Eating quality of electrically stimulated grass fed lamb, processed to strict hygiene standards and wrapped in plastics, is essentially unchanged for at least two years storage at -10°C (14°F) (Winger, 1984). In ground beefburgers the critical quality attribute may be a lack of balance in the spices present. Pepper flavour persists well in cold store whereas other spices diminish in intensity. A high pepper note may indicate this lack of balance long before rancidity sets in. The lack of clear and unambiguous data on the shelf lives of meats, which is

ascribed to differing definitions of the end of storage life, is clearly seen in a review by Evans and James (1993).

15.3.4 Bakery products

If seafood loses quality within days of capture bakery products lose freshness within a few hours of being removed from the oven. Freezing is an obvious method to preserve 'fresh from the oven' characteristics were it not for the need to traverse the chill temperature zone twice, on freezing and again when thawing. Quality loss, through starch retrogradation, occurs most rapidly at chill temperatures in baked goods. Slow freezing is to be avoided in order to reduce the time spent at chill temperatures. Despite this constraint a well formulated, frozen, stored and refreshed bakery product (regardless of the time spent in frozen storage) has sensory properties comparable with the same (unfrozen) product less than one day after baking (Stauffer, 1992). Amylase is a useful antidote to bread staling. Moisture migration during frozen storage is the principal cause of staling in general. With careful formulation, strict regard for the first 'P' coupled with modifying production and handling techniques, the second 'P', can guard against these defects. Cooling before freezing is important for stability: a hot bakery product placed in a blast freezer will result in an ice rind formed just below the crust surface, which will become detached on slicing. Some bakery products, notably croissants, are difficult to formulate to enable them to be frozen without becoming leathery and losing their fresh aroma. The open interior of the product mitigates against rapid freezing.

Yeast cells do not withstand freezing well. Yeast raised products have some of the lowest stabilities of any frozen foods. This can be partially compensated for by increasing the amount of yeast used in the formulation; new and improved yeast strains exhibit a better survival rate in freezing.

15.3.5 Prepared products

Complex multi-component products not only bring all the problems of the stability characteristics of each component but a few extra, such as aroma migration between the components and the likelihood of spaces being present in the package, leading to easy access for oxygen. If fluctuating temperatures are encountered moisture migration from a high water activity component to a low one may result in grave quality defects. A common complaint concerning frozen multi-component prepared foods is a lack of, or 'sameness', of flavour. This is probably due to the beginning of aroma migration between the components, the more highly flavoured component transmitting flavour to the bland ones so that a depressing

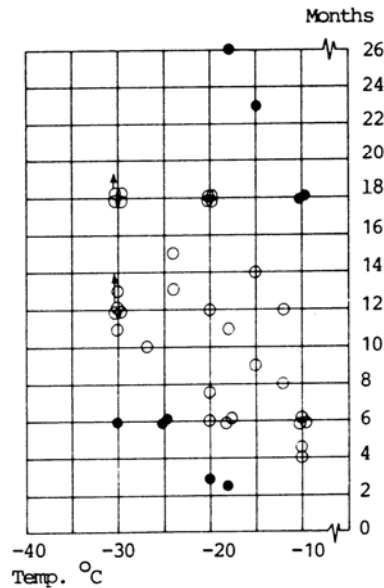


Figure 15.4 Shelf life data for ready-to-eat meat dishes as reported by various authors, as collected by Spiess, and quoted by Jul (1984). (Source: M. Jul, 1984. In: Thermal processing and quality of foods, Zeuthen *et al.* (eds), 1984.)

uniformity in flavour results. 'Sameness' of flavour should be noted as possibly the first perceptible difference in many products. Otherwise the rule of assessing stability of multi-component products is to identify the most thermo-labile component and its most sensitive quality attribute and concentrate on assessing this as an indicator of JND. Figure 15.4 illustrates the enormous degree of variability reported by various authors in the shelf life of ready-to-eat frozen meat dishes.

15.4 The cold chain

The final decision as to the likely shelf life of a given frozen product must take account of the fact that the product is not going to be stored at a steady temperature of -18°C (0°F) from the end of freezing until thawing for consumption or during end cooking. A typical frozen product will spend part of its shelf life in a bulk cold store, a refrigerated vehicle or container, a distribution store, a retail display cabinet or institutional frozen food storage cabinet, a period out of refrigeration during the journey from the retail outlet to home and time in a home freezer or star-marked frozen food storage compartment, before being consumed in the

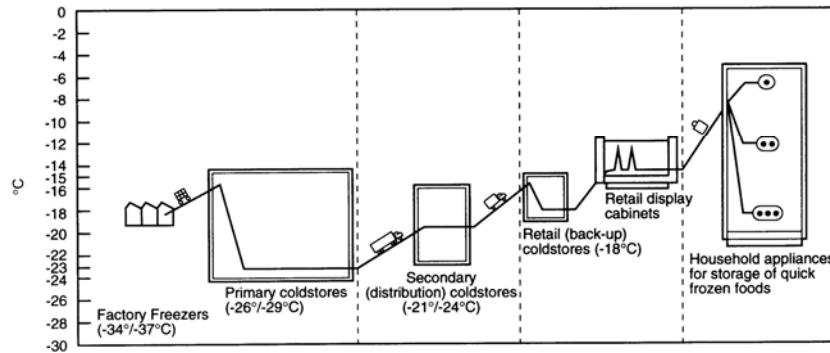


Figure 15.5 Temperature profile of the cold chain. (Source: Sanderson-Walker, 1984. In: Thermal processing and quality of foods, Zeuthen *et al.* (eds), 1984.)

frozen state, thawed or end cooked. Figure 15.5 illustrates the various components of a typical cold chain in Europe where 'star marked' frozen food storage compartments are common in household refrigerators.

An essential part of any shelf life determination in markets where 'star marked' frozen food storage compartments are in use is to assess the shelf life at the relevant temperatures for '1-Star', -6°C (21°F) and '2-Star', -12°C (10°F).

15.4.1 Temperature monitoring

There is a plethora of indicating and recording devices to enable product temperatures to be monitored throughout distribution; from simple indicating thermometers to computerised recorders which can be buried in loads where they record temperature every 15 minutes, the complete record being read out on a computer within a minute or so at the end of the journey or period in storage. Refrigerated vehicles can be fitted with transmitters which enable the dispatcher to call up the vehicle at any time and discover its location and load temperature without any need for intervention by the driver.

15.4.2 Time-temperature indicators

The literature is replete with over five hundred patents for freeze-thaw indicators and temperature limit indicators as well as time-temperature integrators. Few have been brought to market and none has achieved an enduring success. Some are unwieldy or expensive; the best are inexpensive, costing a few pennies each, but, despite numerous trials in products

as diverse as cut flowers, vaccines, ice cream, frozen military rations or frozen sous vide products, no sustained successful use has yet been announced. Trials seem always to be abandoned even if the device itself performs its task adequately.

More attention is being paid to frozen food temperatures in Europe in the wake of the EC Directive that mandates specific temperatures for various commodities throughout the cold chain. The need for this law was long disputed on the grounds that such temperatures have little, if anything, to do with health, are only concerned with quality and that temperature at any particular moment is an imperfect indicator even of quality.

15.4.3 Control of time in storage

Frozen foods, well formulated, correctly processed and adequately packaged have a very long cold storage life at sufficiently cold temperatures but nothing is for ever. Some system of control is required over the time spent in the various segments of the cold chain. This calls for control over pallets, control over the cases of product and, finally, over the individual packages.

Control over pallets is generally achieved by the computerised recording system of the producer in concert with the bulk storage facility. Control over cases is achieved in Europe by printing the mandatory open shelf life date which is demanded on individual packets on the outer case in standard format. In the USA no such assistance is provided to the supermarket store clerk who may have to choose between two identical cases to be placed in the display cabinet. Production codes in cryptic form do not help much. In countries where open shelf life dating is mandated, such as in the EC, a minimum durability, 'best before' or final consumption date is printed on the consumer package together with the relevant 'star marking' storage instructions. In the USA some producers give a shelf life date on individual packets but, over the years, there seems to have been little consumer reaction. Labuza (1982) gives the rationale for open shelf life dating on consumer packets as an aid to engendering consumer confidence and supplying the consumer with useful information. In the absence of a temperature history this information can be misleading. Opponents to mandatory open shelf life dating on consumer packets allege that this will give undue prominence to time to the detriment of maintaining adequate temperatures which is immeasurably more important to frozen food quality. Also when more than one date is on display very few, if any, prospective customers will select the earlier date; most will ignore the date while a few will 'rummage' for the latest date, upsetting the 'FIFO' (first in, first out) principle of stock rotation. Placing a date on the consumer package also gives the erroneous impression that

frozen food quality expires suddenly whereas it is more likely to decline very slowly over long periods if held at the required temperature.

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