Review

Determination of Microbial Shelf Life of Food—A Review

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The modern food industry has developed and expanded because of its ability to deliver a wide variety of high quality food products to consumers on a nationwide and worldwide basis. This feat has been accomplished by building stability into the products through processing, packaging, and additives that enable foods to remain fresh and wholesome throughout the distribution process. Total quality is the paramount importance and consumer's perception on the product is the ultimate measure of total quality. The quality of most foods decreases over time; in other words, there is a continual loss of quality from the time they leave the food processor until they are consumed, even under ideal handling conditions. Shelf-life studies can provide important information to minimize the extent of quality degradation to product developers enabling them to ensure that the consumer will see a high quality product for a significant period of time after production.

Introduction

Consumers are increasingly demanding consistently high food quality, and have corresponding expectations that such quality will be maintained at a high level during the period between purchase and consumption. These expectations are a consequence not only of the primary requirement that the food should remain safe, but also of the need to minimize unwanted changes in sensory quality. The quality needs are reflected in the labeling requirements to which food manufacturers must conform. In the UK, the date coding to be used is determined by the total life of the product: for microbiologically highly perishable foods, a

'use by' date is needed, while for other foods, including foods with more than 18 months' shelf-life, a "best before" or a "best before end" date is needed. In general, microbiological changes are of primary importance for short-life products, and chemical and sensory changes for medium- to long- life products; all three types can be important for short- to medium- life products¹²⁾.

Shelf life is defined as the time during which the food product will i) remain safe; ii) be certain to retain desired sensory, chemical, physical and microbiological characteristics; iii) comply with any label declaration of nutritional data, when stored under the recommended conditions⁸⁾.

The definition succeeds in identifying the key factors that must be considered when assessing shelf-life, but again leaves interpretation of the words 'desired... characteristics' highly ambiguous. The ambiguity perhaps reflects and important consideration. Except in situations in which microbiological safety is an issue, the definition of shelf-life is related to the positioning of the product in the market in terms of quality and consumer perceptions of that quality. For example, an economy product that, following manufacture, has a lower quality index than a premium product, does not necessarily have a shorter shelf-life, even if the deterioration rate is the same. Consumers of a premium product will have greater expectation of quality over the entire shelf life period. Alternatively, it is possible to picture a situation in which a premium product at the end of its shelf-life has a higher perceived quality than an economy product at the start of its storage life. The IFST (Institute of Food Science and Technology) definition also raises the important issue of storage conditions on products

shelf-life. Measurement of storage characteristics takes place under carefully controlled environmental conditions that are rarely met in practice, especially once the product has left the retail environment. Thermal abuse in the distribution chain is common, but becomes almost routine in a domestic environment³⁾. Ambient temperature conditions in the kitchen vary widely, and temperature control in domestic refrigerators and freezers is frequently poor. It is therefore important for the food manufacturer to have an understanding of the storage characteristics of the product under a wide range of storage conditions, and even under the fluctuating or cyclical conditions that are commonly encountered in practice in the supply chain. If the behaviour of the product on storage is to be understood, it is equally important for the manufacturer to have a thorough understanding of the mechanism of the deterioration process(es), which can be complex in many foods, especially those with composite structures⁹⁾.

Shelf-life Estimation

There are at least three situations when shelf life estimation might be required:

1. To determine the shelf life of existing products
2. To study the effect of specific factors and combinations of factors such as storage temperature, packaging materials, processing parameters or food additives on products shelf life.
3. To determine the shelf life of prototype or newly developed products.

Several established approaches are available for estimating the shelf life of foods¹⁷⁾:

1. **Literature study:** the shelf life of analogous product is obtained from the published literature or in-house company files. Examples can be found in recent books on the shelf life of foods^{7, 9, 11)}.
2. **Turnover time:** the average length of time that a product spends on the retail shelf is found by monitoring sales from retail outlets, and from this the required shelf life is estimated. This does not give the “true” shelf life of the product but rather the “required” shelf life, where it is

implicitly assumed that the product is still acceptable for some time after the average period on the retail shelf.

3. **End point study:** random samples of the product are purchased from retail outlets and then tested in the laboratory to determine their quality. From this, a reasonable estimation of shelf life can be obtained because the product has been exposed to actual environmental stresses encountered during warehousing and retailing.
4. **Accelerated Shelf life testing:** laboratory studies are undertaken during which environmental conditions are accelerated by known factor so that the product deteriorates at a faster than normal rate. This method requires that the effect of environmental conditions on product shelf life can be quantified.

Factors Influencing Shelf-life

Many factors can influence shelf-life, and can be categorized into intrinsic and extrinsic factors. Intrinsic factors are the properties of the final product. They include the following:

Water activity (a_w) (available water)
 pH value and total acidity; type of acid
 Redox potential (Eh)
 Available oxygen
 Nutrients
 Natural microflora and surviving micro-biological counts
 Natural biochemistry of the product formulation (enzymes, chemical reactants)
 Use of preservatives in product formulation (e.g. salt)

Intrinsic factors are influenced by such variables as raw material type and quality, and product formulation and structure. Extrinsic factors are those factors the final product encounters as it moves through the food chain. They include the following:

Time-temperature profile during processing; pressure in the headspace.
 Temperature control during storage and distribution
 Relative humidity (RH) during processing, storage and distribution.
 Exposure to light (Ultraviolet and Infrared) during processing, storage and distribution.

Environmental microbiological counts during processing, storage and distribution.

Composition of atmosphere within packaging

Subsequent heat treatment (e.g. reheating or cooking before consumption)

Consumer handling

All these factors can operate in an interactive and often unpredictable way, and the possibility of interactions must be investigated. A particularly useful type of interaction occurs when factors such as reduced temperature, mild heat treatment, antioxidant action and controlled atmosphere packaging operate in concert to restrict microbial growth. This way of combining factors which, individually, are unable to prevent microbial growth but, in combination, provide a series of hurdles, which do so, allow manufacturers to use milder processing techniques that retain more of a products sensory and nutritional properties.

The interaction of such intrinsic and extrinsic factors as these either inhibits or stimulates a number of processes, which limit shelf-

life. These processes can be conveniently classified as:

Microbiological

Chemical

Physical

Temperature related

Type of Deterioration That Limit Shelf Life

The factors described above can result in a wide range of deteriorative changes, and these will depend on the food type. Table 1 shows some examples of the main deteriorative changes in a variety of food classes, and the consequential factors limiting shelf life. In composite foods the factor limiting shelf life can be quite different from those that limit the shelf life of the individual components. For example, an important factor limiting shelf life in breakfast cereals containing a mixture of cereals and dry fruit is the hardening of the fruit from moisture migration into the cereal. In contrast, the limiting factors for the individual fruit and cereal components would be flavor changes arising from chemical reactions and moisture uptake and softening of the cereal.

Table 1. Deterioration of some selected food products

Product	Deterioration mechanisms	Limiting changes
Fresh red meal	Oxidation, microbial growth	Loss of red color, rancidity, off-odors and flavors
Fresh fish	Microbial growth, chemical reactions	Microbial, off-odors, appearance changes
Fresh poultry	Microbial growth	Microbial, off-odors
Fresh sausages	Microbial growth, oxidation	Microbial, rancidity
Fresh bacon	Microbial growth, oxidation	Microbial, rancidity, color change
Soft fruit	Enzymic breakdown, mould growth, moisture loss	Textural softening, visible mould, dry appearance
Hard fruit	Enzymic action, moisture loss	Textural softening, bruising, dry texture
Dried fruit	Enzymic action, chemical reactions	Browning, flavor changes
Potatoes	Enzymic action, sprouting	Softening, poor cooking, sprouting toxin production
Cucumber	Enzymic action	Loss of crispness, gross structure breakdown
Coleslaw	Moisture loss from vegetables fat oxidation	Loss of viscosity in dressing, appearance changes, microbial growth, rancidity
Cakes	Moisture loss, starch changes, microbial growth	Drying and hardening, stale flavor and texture, mould formation.
Bread	Starch retrogradation, moisture migration	Stale texture and flavor, dry texture, mould growth
Breakfast cereals	Moisture migration, Starch retrogradation, oxidation	Softening (cereal), hardening (fruit), stale texture and flavor, rancidity
Spices	Microbial growth, volatile loss, chemical reactions	Mould and bacterial growth, flavor changes, color loss.
Fruit juices	Oxidation, microbial growth, enzymic reactions	Flavor and nutrient loss, microbial, cloud instability.
Beer	Oxidation, microbial growth	Off flavors, turbidity
Tea	Volatile loss, volatile absorption	Flavor loss, off-flavor
Coffee	Volatile loss, oxidation	Flavor change, rancidity
Wine	Oxidation	Off flavor, color changes

Microbiological changes

Growth of a specific microorganism during storage depends on several, the most important being: the initial microbial loading at the start of storage; the physicochemical properties of the food, such as moisture content, pH, presence of preservatives; the processing method used in the production of the food; and the external environment of the food, such as the surrounding gas composition and storage temperature. A number of key intrinsic and extrinsic factors affecting the growth of some key pathogens and spoilage organisms are shown in Table 2. It is important to note that this table lists approximate growth limits with the various factors acting alone. Interactions between these factors may alter these limits considerably⁹⁾.

The growth of food-poisoning organisms such as *E. coli* O157:H7, *Salmonella* species and *Listeria monocytogenes* will not necessarily be accompanied by changes in appearance, odour, flavour or texture that could be detected by human senses, and consequently pose serious health concerns. Growth of spoilage organisms is often readily identified by sensory changes, for example visual mould growth, generation of off-odours and flavours and changes in texture, frequently from the action of enzymes produced by microorganisms.

Chemical deteriorative changes

Many important deteriorative changes can occur arising from reactions within the food or

from reactions of food components with external species, for example oxygen. Rancidity development is an important factor in fat-containing foods, and can occur via different mechanisms, for example lipolytic/hydrolytic reactions, oxidative reactions and flavor reversion reactions. Enzymic process limit the shelf-life of fruits and vegetables, and oxidation reactions limit the shelf-life of meat. Chemical hydrolysis can occur in products containing intense sweeteners, reducing sweetness, and non-enzymatic browning can occur in many foods from Maillard reactions. Changes can also occur on exposure to light, including color loss in natural food colours and rancidity and off flavor development in milk and in snack foods.

Physical deteriorative changes

Moisture migration is a major cause of deteriorative physical changes in food. This is easily seen in fresh produce through moisture loss, and dry products such as breakfast cereals and biscuits can lose their crispness through moisture uptake. Delicatessen salads can also deteriorate from migration of water from the vegetable component into the dressing. Freezer burn is also a consequence of moisture migration from the surface of frozen foods. Other migration phenomena can limit shelf-life, particularly of more complex composite foods, such as migration of fat from one component to another, and the bleeding of colours in composite products such as chilled desserts. Physical

Table 2. Minimum growth conditions for selected microorganisms

Type of microorganisms	pH	a_w	Anaerobic growth	Temp. (°C)
Pathogens				
<i>Bacillus cereus</i>	4.4	0.91	Yes	<4
<i>Clostridium botulinum</i>				
Proteolytic A, B, F	4.6	0.93	Yes	10
Non-proteolytic B, E, F	5.0	0.97	Yes	3.3
<i>Escherichia coli</i>	4.4	0.95	Yes	7
<i>E. coli</i> O157:H7	4.5	0.95	Yes	-6.5
<i>Listeria monocytogenes</i>	4.3	0.92	Yes	0
<i>Salmonella</i>	4.0	0.94	Yes	7
<i>Staphylococcus aureus</i> (toxin)	4.0(4.5)	0.83(0.90)	Yes	-6(10)
<i>Vibrio parahaemolyticus</i>	4.8	0.94	Yes	5
<i>Yersinia enterocolitica</i>	4.2	0.96	Yes	-2
Spoilage organisms				
<i>Enterobacter aerogenes</i>	4.4	0.94	Yes	2
Lactic acid bacteria	3.8	0.94	Yes	4
<i>Micrococci</i>	5.5	0.97	No	4
Moulds	<2.0	0.60	No	<0
<i>Pseudomonas</i>	5.5	0.97	No	<0
Yeasts	1-5	0.80	Yes	-5

changes in packaging materials, sometimes coupled with subsequent chemical reactions can also limit sensory shelf life. As an example, permeability changes with time can change the in-pack equilibrium atmosphere, giving rise to both microbiological and chemical effects. Such changes may also allow migration of external volatiles into the food, resulting in the development of taint. Migration of chemical components from the packaging material can also produce taints, and this can be particularly serious in products with a long shelf life.

Temperature Related Deteriorative Changes

Deterioration can occur at both elevated and depressed temperatures. The minimum growth temperatures for a range of pathogen and spoilage organism presented in Table 2 illustrates the importance of effective temperature control in preventing microbial contamination and spoilage. Increasing the temperature generally increase the rate of chemical reactions that may result in deterioration. In food containing fat, more solid fat will become liquid and act as a solvent for reactions in the oil phase, and changes in fat crystallinity can occur, for example, producing bloom in chocolate. Increased temperature can also change the crystallization characteristics of foods containing sugar syrups. Destabilization of emulsion systems can also occur under conditions of fluctuating temperature and mechanical agitation. Fluctuating temperatures can cause ice crystal formation in frozen foods such as ice-cream. In contrast, increased temperatures can reduce the development of staling in bread, although the situation with other baked food can be complex and unpredictable.

Determining End of Shelf Life

The most direct way of determining the end of shelf life is to conduct properly constructed storage trials under realistic, defined conditions. Indirect methods are also frequently be used and are often faster and just as effective. These are often referred to as accelerated shelf life tests, and are usually based on storage of the product at higher than normal temperatures. The use of computer-based predictive models can also assist in accelerated testing by reducing the number of variables

and samples that need to be tested, and therefore reduce the cost and time necessary.

No single factor can be relied on to determine shelf life, whether microbial, chemical or organoleptic. Shelf life determination requires an evaluation of all of these parameters, and cannot be determined by guesswork or by copying the shelf life of a similar product from another source. Once a full evaluation has been performed, it may be determine that one of these factors can be used as effective predictor of product shelf life. (A guide of the application of date marking of food: <http://www.afgc.org.au/cmsDocuments/AFGC%20Guide%20to%20Date%20Marking%20of%20Food%20-%20Sept08.pdf>)

Shelf life is specific for a food made on a particular site as it is affected by:

- initial microbial levels, lag times and microbial strain variations
- quality and composition of ingredients used.
- product formulation
- processing conditions (e.g. heating, dehydration, fermentation, acidification, etc.)
- packaging type
- storage conditions

Packaging type, including the use of modified atmosphere gases in packaging, plays an integral part in the shelf life of a food. For example, if in a particular market segment a manufacturer determines that a shelf life of only six weeks is necessary, it may be possible for the product to be successfully packed in a plastic with lesser barrier properties than if the manufacturer was seeking a six month shelf life. In either case, the expected shelf life will be dependant on the integrity of the packaging to maintain the atmosphere.

In undertaking an assessment of shelf life, there needs to be a clear understanding of the following parameters:

- criterion for when the product is determined to be unsafe
- criterion for unsuitability
- acceptable frequency of non-compliance
- reasonable time for consumer use in the case of best before date

The evaluation of microbial parameters is

one of the key criteria on which to determine shelf life and safety. Challenge testing may be used to determine if pathogens will be controlled or eliminated by the processes used in manufacturing, or to estimate the time it takes for them to grow to potentially hazardous levels in perishable foods.

Challenge testing using potential spoilage organisms can also be used for shelf life studies. There can be a direct and predictable relationship between the level to which spoilage organisms have grown in a food and the loss in quality of the food, but the rate at which this occurs is specific to the food, its formulation and its environment. In perishable foods, degradation moves rapidly from a slight loss of quality to unfit for consumption.

Microbial spoilage is an exponential process which, in a relatively small period of time, can change a product with a slight loss of quality to one with an unacceptable loss in quality and the presence of a substantial number of spoilage organisms, thus quickly rendering the food unfit for consumption (Fig. 1). Packaging integrity, the presence of growth inhibitors and microbial growth conditions will influence the rate at which such degradation will occur, and this makes it difficult to accurately predict how long after the best before date the food may last. Quality loss of a shelf stable food may merely result in staling, which can be assessed chemically or organoleptically (Fig. 1).

Shelf Life Testing

The first step in shelf life testing requires identifying the microbial hazard in food. For example, the presence of *L. monocytogenes* has been recognized as a potential hazard in ready-to-eat (RTE) refrigerated foods, including sushi and sashimi, and those consumed without cooking that could include refrigerated, precooked shrimp products. The prevalence of non-proteolytic *C. botulinum* and its toxin in partially cooked fishery products packaged under vacuum or modified atmosphere would also present a safety hazard and defined shelf life.

Once the hazard is identified, the growth kinetic parameters of the identified pathogen are calculated based on its growth to a specific regulatory level under refrigeration and temperature-abuse conditions in the foods of interest. The legal tolerance levels for pathogen and spoilage microorganisms in foods, however, differ by country.

Challenge testing

In a challenge study, the product is inoculated with known spoilage microorganisms. The inoculated samples are then treated and stored in accordance with the shelf-life study guidelines. Adding organisms to the foods adds several more variables to the study. The types of organisms and the number of strains of each type to be used need to be decided. In addition, an inoculation level must be selected. The

Fig. 1. Relationship between microbial spoilage, quality loss and end of shelf life. Changes in spoilage organisms and metabolites produce by specific spoilage organism, and changes in quality parameters under certain storage conditions can be used as microbiological and organoleptic indices of spoilage.

spoilage organism used in the challenge study is usually one that has been isolated previously from similar foods that have spoiled. For example, lactobacilli and yeast are the most common spoilage organisms of salad dressings and sauces. The more isolates included in the challenge study, the greater will be the confidence in the accuracy of the shelf-life assessment. In practice, five isolates of lactobacilli, five of yeast, and five of mold represent a reasonable selection for a salad-dressing challenge study. (Microbial Shelf-Life Testing: <http://www.foodproductdesign.com/articles/1998/02/limiting-growth-microbial-shelf-life-testing.aspx>)

The number of organisms added to the food is generally significantly higher than what would normally be found as a result of contamination during processing. The inoculation levels used are generally greater than 10 CFU/g, offering easy observation of the presence of the challenge organisms; 10 CFU/g represents the limit of sensitivity of the agar plate count procedures normally used for enumeration. Lower levels can be detected, but usually at significantly greater expense and with lower accuracy.

When the level of the challenge organisms does not increase during shelf-life storage, the product formulation is resistant to microbial growth. It is stable in the sense that the number of microorganisms does not increase. However, if the organisms are present in sufficient number, it is still possible that the metabolic activity of the non-growing cells will cause undesirable changes in the product.

In most foods susceptible to spoilage, the organisms do not begin to multiply immediately. Instead, the count remains relatively constant for a period of time before growth is observed. The period of no growth is analogous to the lag phase of the microbial growth cycle. A fraction of the challenge organisms may die soon after being added to the test sample.

If the sample has a low initial inoculation level and die-off occurs, one might incorrectly conclude that the product is stable. Using high inoculation levels will prevent this error. A level of about 10,000 CFU per gram is useful for observing either decreases or increases in levels, even if an initial 100-fold die-off is observed.

Die-off after inoculation most likely results from shock caused by an abrupt change in environment for which the cells are not pre-conditioned. The die-off can sometimes be avoided or reduced by first adapting the organisms to the product's nutrients, acidity or water activity. In the real world, contamination of product by both unadapted and adapted organisms occurs. The use of organisms that are not specifically adapted for growth in the product simulates organisms originating in the environment and entering the food through contact. Adaptation simulates product-to-product contamination¹⁴.

Challenge studies using pathogens are conducted to measure the behavior of those microorganisms in foods and formats similar to studies in which spoilage microorganisms are used. The purpose for using pathogens is to measure their growth, inhibition or die-off in a food. Commonly used pathogens are *Salmonella*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium perfringens*, *Yersinia enterocolitica*, *Clostridium botulinum*, and *Escherichia coli*. If the pathogens do not grow, the food is considered stable with respect to the ability of the food system to inhibit their growth.

Inhibiting changes in the organism's environment influences the duration of the lag phase of the pathogens. The greater the inhibition, the longer the lag phase. Even shifts in incubation temperature between that used to propagate the organism for the study and the storage temperature of the product may change the length of the lag period. Therefore, the organisms' preparation conditions must be carefully chosen to account for a study's specific needs.

Accelerated shelf life testing

The basic assumption underlying accelerated shelf life testing (ALST) is that the principles of chemical kinetics can be applied to quantify the effects which extrinsic factors such as temperature, humidity, gas atmosphere, and light have on the rate of deteriorative reactions. By subjecting the food to controlled environments in which one or more of the extrinsic factors is maintained at a higher than normal level, the rates of deterioration will be accelerated, resulting in a shorter than normal

Table 3. Time to complete an ASLT test for a low moisture food product of two years targeted shelf-life at ambient storage depending on the temperature sensitivity (E_A) of the shelf-life determining reaction¹³⁾

E_A kJ/mol	Testing time at 40°C ASLT storage temperature	Testing time at 45°C ASLT storage temperature
45	224 days	171 days
85	78 days	47 days
125	28 days	13 days

time for product failure. The magnitude of the acceleration can be calculated and the true shelf life of the product under normal conditions calculated^{2, 10)}.

Shelf life studies and ASLT require a profound knowledge of the constituents of the food, the process, the microbial safety factors, the main modes of quality deterioration and the intended storage conditions. With effective use of ASLT, an experiment that normally takes a year can be completed in about a month, if testing temperature is raised by 20°C. The duration of the shelf life determination by ASLT depends on the temperature sensitivity (E_A) of the quality deterioration phenomena as is shown in Table 3.

This model is only appropriate for simple chemical systems, however, and often fails for complex foods, for example in bread, where an increase in temperature decreases the rate of staling reactions. Some of the processes that can take place at elevated temperatures and that change the deteriorative processes including increased water activity, denaturation of proteins, decreased solubility of gases, crystallization of amorphous carbohydrates, changes in chemical reactions, melting of fats, and change in solvent properties.

The overall effect of such processes on quality is often not predictable, and can lead to either under or overestimated shelf-life predictions.

It is therefore important to test the validity of any accelerated conditions against known deterioration characteristics under ambient storage conditions, and to establish the limits of the reliability of any relationship found. If time pressures do not allow the identification of the ambient storage characteristics of a product, then comparisons can sometimes be made between the test product and an equivalent prod-

uct of similar structure and for which a shelf life has previously been established. Although there are many questions regarding the reliability of accelerated tests, when carefully designed these can be used as a valid measure of storage performance under the abuse conditions that can be encountered in the distribution chain and in the domestic environment.

Predicting Microbial Shelf Life

Predictive microbiology involves knowledge of microbial growth responses to environmental factors summarized as equations or mathematical models. The raw data and models may be stored in a database from which the information can be retrieved and used to interpret the effect of processing and distribution practices on microbial proliferation. Coupled with information on environmental history during processing and storage, predictive microbiology provides precision in making decisions on the microbiological safety and quality of foods. The term “quantitative microbial ecology” has been suggested as an alternative to “predictive microbiology”¹⁵⁾.

Microbial spoilage of food is an economically significant problem for food manufacturers, retailers, and consumers. Depending on the product, process, and storage conditions, the microbiological shelf life can be determined by either the growth of spoilage or pathogenic microorganisms. In case of spoilage microorganisms, the traditional method for determining microbiological shelf life involved storing the product at different temperatures and determining spoilage by sensory evaluation or microbial count. Where pathogenic microorganisms determine the microbiological shelf life, the traditional approach has been challenge testing of the product with the organism concern, followed by storage at different temperature and microbial analysis at certain intervals.

For process such as heat treatments, where the elimination of a particular microorganism is required (e.g. canning), the use of inoculated pack is common.

In recent years, the development and commercialization of predictive models has become relatively widespread. The use of such models can reduce the need for shelf life trails, challenge tests, product reformulations and process modifications, thus saving both time and money. Although there are mechanistic and empirical predictive models, the latter predominate. Empirical predictive models can be subdivided into probabilistic and kinetic models⁵⁾. Probabilistic models describe the probability of a microbiological event occurring, and are used to predict whether certain microorganism will grow when they are close to their growth boundaries (e.g. whether *C. botulinum* will grow and produce toxin). The ultimate test for predictive models is whether they can be used to predict reliable outcomes in real situations.

Predictive models has been used to determine the likely shelf life of perishable foods such as meat, fish, milk and recent publications in the area have been reviewed, together with a discussions of limitation of such models^{5, 6)}. Despite their increasing sophistication and widespread availability, models should not be relied completely. Rather, models are best-employed tools to assist decision-making. Models do not completely negate the need for microbial testing, and do not replace the judgment of a trained and experienced food microbiologist.

Modeling Detection Times

The modeling of detection times is thus an important parameter along with the currently measured lag and log phase kinetics for safety-based date labels. To account for growth prediction based on an initial inoculum below detection levels, the growth modeling of pathogens in foods can be based on time to detect (TTD) modeling. The time to detect of *L. monocytogenes* in RTE meats at a given condition has been identified as the time the organism takes to grow from below detectable levels to concentrations that are detectable using standard microbiological techniques (Fig. 2).

Temperature during storage influences the rate of pathogen growth even when it is undetectable, and TTD models must consider the accumulative temperature abuse that occurs between the distribution and consumption of any food. The basic premise of a TTD model should consider that the initial levels of pathogen or toxin are below the detection limit. Thus, the final TTD is 1 CFU/25 g food. Alternatively, the end point could be the time to a safe legal tolerance level of, for example, 100 CFU *L. monocytogenes*/g for RTE foods in the E.U. or Canada^{1, 14)}.

Monitoring and Traceability

Monitoring food throughout the distribution chain is an important factor for traceability and deciding shelf life. A crucial tool for accomplishing this goal is the time-temperature integrator (TTI) tag, which are small, physical devices that are placed on the food package to measure the temperature history of a product

Fig. 2. Microbial growth curve from initial inoculum above and below detection limit.

Fig. 3. Shelf life plot of TTD *botulinum* toxin in fish⁴⁾.

and indicate a definitive change at the end of shelf-life through “integration” of the time temperature exposure, e.g. “Use food by December 30, 2009 unless dot turns red”.

The kinetics (growth as a function of time) and temperature sensitivity (E_A) (increase in growth rate with temperature, called Q_{10}) of pathogens in foods can be combined in an algorithm that can predict shelf life by the integration of the duration the food is exposed to different temperatures between production and consumption (Fig. 3)¹⁶⁾.

Thus, the use of both chemical-based and electronic TTIs takes temperature fluctuations into account and indicates the end of shelf life by easy-to-read, time and temperature-dependent chromogenic changes or light-emitting diode output once the growth level of a pathogen reaches the detection or tolerance level. Today, with radio frequency identification (RFID) and electronic sensing and broadcasting capabilities, the limitations of chemical tags have been supplanted, since these tags can mimic all phases of microbial growth.

Expiration Regulations

The U.S. Food and Drug Administration require expiration dating on prescription drugs, some over-the-counter drugs, and infant formula. Putting an open date on other food products is voluntary. Currently 30 U.S. states regulate open dating, mainly for dairy and meat products, with the principle purpose commerce and not food safety. Some food products in Denmark are required to list a pack date, sell-by date, and use-by date, thus satisfying both re-

tailer and consumer demands. Open dating as required by the European Union’s Directive 97/4/EEC, Article 9 of 79/112/EEC does not directly indicate safety from pathogen growth in foods, but requires dating for foodstuffs that are perishable due to microbiological growth and therefore likely to present an immediate danger to human health. In such cases, the date of minimum durability is replaced by a use-by date¹⁾. In Japan, labeling is mandatory for all producers, distributors and other parties to label in accordance with the Quality Labeling Standards established by the Minister of Agriculture, Forestry and Fisheries, and Food Sanitation Standard established by the Ministry of Health, Labor and Welfare, except for liquors, drugs, quasi-drugs and cosmetics. Both the “best before” and “Use by date” labeling are followed depending on the food products according to JAS Law and the Food Sanitation Law (Food labeling & Japanese Agricultural Standard (2009): <http://www.maff.go.jp/e/jas/index.html>).

Conclusion

The quality of most foods decreases over time; in other words, there is a continual loss of quality from the time they leave the food processor until they are consumed, even under ideal handling conditions. The goal of modern food distribution techniques is to minimize the extent of quality degradation so that the foods will reach the consumer’s table as close to their original state as possible.

Of all the extrinsic factors that accelerate quality degradation, the one with the greatest

influence is temperature. This fact is well known and most countries have code of practice that specifies optimum storage temperatures for many foods, particularly those classified as perishable. Despite these specifications, problems of storage temperature abuse arise too frequently. One difficulty when storage temperature abuse is suspected lies in detecting the extent of the quality degradation without sampling the food (i.e. Distribution the integrity of the package). An associated difficulty is that many of those involved in the distribution chain are not trained to make reliable judgments about the quality of the food.

Thus food processors require a simple way of indicating whether their products have been stored at undesirable temperatures, or better still, a means of indicating how much shelf life remains. Time-temperature indicators (TTI) can provide information of abused temperature to the food processors.

References

- 1) National Advisory Committee on Microbiological Criteria for Foods: Considerations for establishing safety-based consume-by date labels for refrigerated ready-to-eat foods. *J. Food Prot.*, **68**, 1761–1775 (2005).
- 2) Robertson, G. L.: Shelf Life of Food. *Food Packaging-Principles and Practice*, 2nd ed. p. 225–254, CRC Press, Boca Raton, FL (1998).
- 3) Audits International: 1999 U.S. Food Temperature Evaluation, Design and Summary Pages. FDA, USA (1999).
- 4) Baker, D. A. and Genigeorgis, C.: Predicting the Safe Storage of Fresh Fish under Modified Atmospheres with Respect to *Clostridium botulinum* Toxigenesis by Modeling Length of the Lag Phase of Growth. *J. Food Prot.*, **53**, 131–140 (1990).
- 5) Blackburn, C. deW.: Modeling shelf life. The stability and shelf-life of food. Kilcast, D. and Subramaniam, P. (eds.), p. 55–75, CRC Press, Boca Raton, FL (2000).
- 6) Dens, E. J. and Van Impe, J. F.: Modelling applied to foods—Predictive microbiology for solid food systems. *Food Preservation Techniques*. Zeuthen, P. and Bogh-Sorensen, L. (eds.), CRC Press, Boca Raton, FL (2004).
- 7) Food shelf life stability—Chemical, Biochemical and Microbiological Changes, Eskin, N. A. M. and Robinson, D. S. (eds.), CRC Press, Boca Raton, FL (2001).
- 8) Shelf life of foods—Guidelines for its determination and prediction. Institute of Food Science and Technology, London (1993).
- 9) Kilcast, D. and Subramaniam, P.: Introduction. The stability and shelf-life of food. Kilcast, D. and Subramaniam, P. (eds.), p. 1–19, CRC Press, Boca Raton, FL (2000).
- 10) Labuza, T. P. and Schmidl, M. K.: Accelerated shelf life testing of foods. *Food Technology*, **39**, 57–64 (1985).
- 11) Shelf-life Evaluation of Foods. 2nd ed. Man, C. M. D. and Jones, A. A. (eds.), Aspen Publishers, Gaithersburg, MD, USA (2000).
- 12) McGinn, C. J. P.: Evaluation of shelf life. *IFST Proceedings*, **15**, 153–161 (1982).
- 13) Mizrahi, S.: Accelerated shelf-life tests. Understanding and measuring the shelf life of food. Steele, R. (ed.), CRC Press, Boca Raton, FL (2004).
- 14) Pal, A., Labuza, T. P. and Diez-Gonzalez, F.: Safety-based shelf life model for frankfurters based on time to detect *Listeria monocytogenes* with initial inoculum below detection limit. *J. Food Prot.*, **72**, 1878–1884 (2009).
- 15) Ross, T. and McMeekin, T. A.: Predictive microbiology and HACCP. HACCP in meat, poultry and fish processing. Pearson, A. M. and Dutson, T. R. (eds.), p. 330–354, Blackie Academic and Professional, London (1995).
- 16) Sherlock, M. and Labuza, T. P.: Consumer perceptions of consumer type time-temperature indicators for use on refrigerated dairy foods. *Dairy Food Environ. Sanit.*, **12**, 559–565 (1992).
- 17) Singh, T. K. and Cadwallader, K. R.: Way of measuring shelf life and spoilage. Understanding and measuring the shelf-life of food. Steele, R. (ed.), CRC Press, Boca Raton, FL (2004).