

Setting Shelf Life: Factors and Insights

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Introduction

The shelf life of a food or drink refers to the period after manufacture that it is safe to consume and is of the intended quality, under the conditions of storage indicated by the manufacturer (1). Food is inherently variable and is in many ways a 'living product'. Therefore, determining this duration with vast and variable supply chains requires an understanding of the interactions between microbiology, formulation, packaging, processing, and distribution. Moreover, establishing shelf life must integrate scientific testing with practical experience from manufacturing and retail environments.

Manufacturers use 'best-before' dates for food categories where quality deteriorates before microbiological safety becomes an issue, e.g. ambient products such as crackers, canned goods and pasta. Alternatively, 'use-by' dates are applied to products that are perishable and high-risk, as they become unsafe microbiologically over a relatively short period, e.g. chilled roast chicken, hummus, and sandwiches (2). Microbiological limits for high-risk foods, at the end of manufacture and during their shelf life, are outlined in retained EU regulations and in UK Department of Health and Social Care (DHSE) guidance (3, 4).

Food businesses (including caterers), that supply products intended for use by the final consumer, are mandated to include a durability date on their product but a business to business (B2B), while not mandated to, must provide their customers with adequate information that allows them to meet their obligations. The shelf life declared by a business governs product safety and quality, but also has sequential effects on supply chain efficiency, food waste, and consumer confidence with financial, sustainability, and reputational implications. An optimised shelf life can reduce waste throughout the supply chain. Evidence-based data, validated under representative conditions, allows a business to minimise the unnecessary disposal of safe food/drink whilst maintaining product safety and quality.

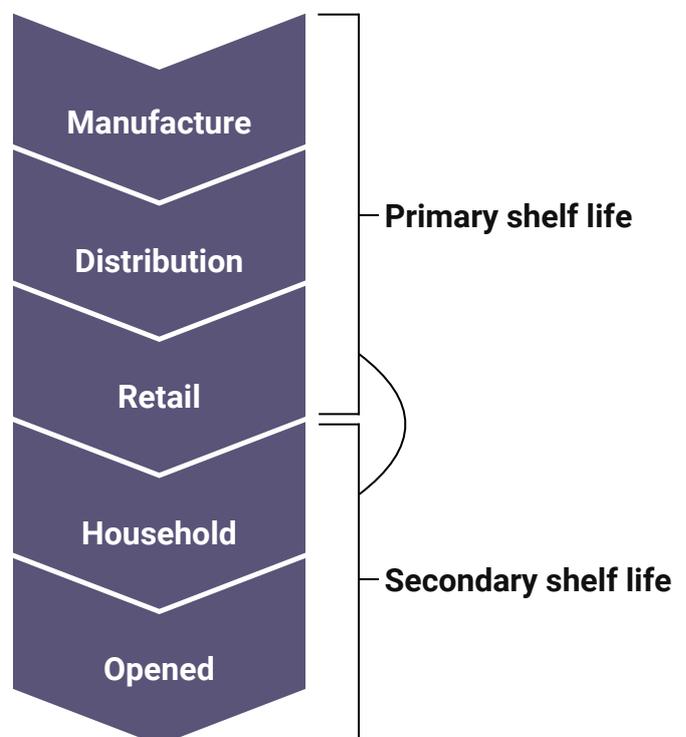


Figure 1: Primary versus secondary shelf life of food/drink products, with potential overlap indicated

Product Composition

The formulation of a food/drink product and a process based on Hazard Analysis Critical Control Point (HACCP) principles are vital for shelf life setting and testing. Overall, a combination of factors come together and interact constructively to reduce microbial (safety) and chemical risks (quality and/or safety) to an acceptable level. Quality-driven shelf life stability factors include lipid oxidation, colour loss, moisture migration, and flavour deterioration. Such physical degradations may also lead to increased microbial risk, for example chemical spoilage may result in pH changes within the product, leading to a change in the evaluated risks, with conditions which may support the growth of different microflora than previously predicted. Sugar, salt, acid, and fat have been used traditionally to preserve foods and extend their shelf life. The use of these solutes in intermediate moisture foods, such as jams, preserves and spreads, allows a sufficient lowering of water activity to slow down microbial growth (5). Products with minimal ingredients listed ('clean label'), and those with reduced salt or sugar, are increasing in popularity amidst ongoing debates surrounding the validity of health impacts and definitions of processed, or ultra-processed foods. Product developers therefore may consider the trade-off between shorter product shelf life, with fewer additives, and product price. To support these efforts whilst minimising food waste, demand forecasting and inventory management techniques must be optimised. In certain product categories where waste is high, other techniques may be required. For example, the incorporation of enzymes, and use of bio-preservatives such as lactic acid bacteria, fermented flours, and sourdough cultures, and other bio-protective cultures have been shown to extend shelf life of bread products (6). In dairy products, the use of live cultures has been shown to prolong shelf life by exploiting the effects of competing

microflora and pH. Product developers have also utilised spices and natural extracts in products to adhere to more 'clean label' characteristics. However, spice powders can have a high bacterial load and would require a pre-heat treatment if they are not added before the cook step of the process. To this end, any reformulation initiatives should be rigorously tested as there may be unintended consequences relating to the product safety, and shelf life.

Microbiological and Quality Considerations

Setting, managing, and monitoring shelf life requires a deep understanding of the supply chain upstream (before the ingredient reaches the factory) and downstream. This allows a business to achieve a realistic simulation of the various modes of transport and changes their product might undergo. A manufacturer must take all reasonable precautions to ensure standardisation of their raw materials: procuring from standard approved suppliers, regular audits of a supply chain, pre-treatment of ingredients to ensure the starting microbiological load is within a reasonable limit of variance that any subsequent hazard reduction process, such as thermal treatment, can eliminate or reduce to an acceptable limit.

Shelf life design aspect	Example variables
Formulation	pH, water activity, salt/sugar concentration, presence/absence of preservatives, e.g. antioxidants, antimicrobials
Manufacture	Pasteurisation, cooling, cooking (time and temperature)
Distribution and retail	Packaging type/properties, temperature control, transport delays, consumer handling

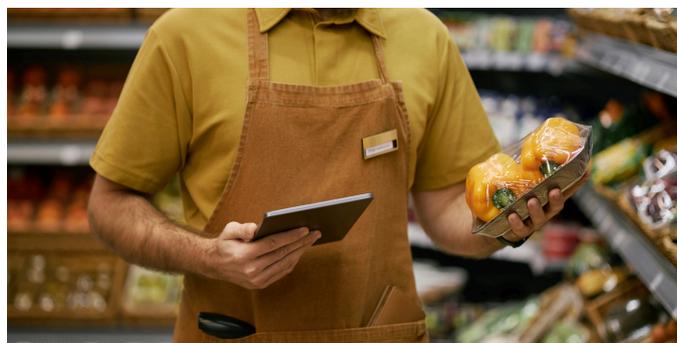
Fresh produce, while not required to have a durability date on it (unless sliced and pre-packed), still requires an internal knowledge of its shelf life for inventory management. The most common principles for retaining the freshness of fruit and vegetables are to control respiration rate through storage variables including temperature, light, and humidity throughout the pre-consumer lifecycle of the product. The importance of seasons, on-farm practices and post-harvest handling have been highlighted in studies, noting that the *Escherichia coli* outbreaks associated with lettuce can be linked to the summer season of harvest due to changes in microflora at the time of harvest and during modified-atmosphere packaging (MAP) shelf life (7).

Testing and Validation: Guidance for Businesses

Shelf life should be built into the product design process, not treated as a compliance step. Collaboration in early development between Research and Development (R&D), quality assurance, packaging, and supply chain teams would facilitate this objective.

Considerations

- Identify the factors most likely to affect product life (ingredient changes, new packaging formats, intermediary freezing, intended conditions of storage and distribution)
- Product development [in the case of artificial intelligence (AI), use for specific and suitable aspects of product development, governance and accuracy tests should be carried out]
- Shelf life design, testing, validation and monitoring (expanded below)
- Practical implementation and post-launch review with post market verification (e.g. retail buybacks, market sampling to test products near end of life)
- Implement a continual review process (monitor regulations, market changes).



Study Design

To get robust data from trials, shelf life design is important. It is useful to conduct all tests in triplicate and with multiple batches of raw materials to capture normal variability and check that the process is adequate. Real-time testing under realistic conditions (temperature, humidity, light exposure, handling) best reflects product behaviour but can be costly and time consuming. Accelerated shelf life testing, using elevated temperatures or other stressors, may be appropriate in early product development, but must be later confirmed under normal conditions. Trials must also be conducted with the 'worst-case scenario' in mind as the age of raw materials can influence their microbial load (11). Risk assessments must account for individual components and steps rather than just the finished product, for example bechamel sauce made in advance as part of a ready-made lasagne dish. Secondary shelf life is also an important aspect and allowing for a certain degree of abuse is a requirement under the Consumer Rights Act, 2005 (12). This may include a consideration of how a consumer may transport a food/drink product from a supermarket to their fridge/cupboard. Temperature logging and sensor technologies can provide dynamic monitoring of product performance over various stages of development, testing, and product launch. Specifications for storage instructions on-pack, and an investigation into shelf life once the pack has been opened (e.g. 'refrigerate after opening', 'once opened, use within x days') requires evaluation with additional shelf life trials.

Knowledge of category norms plays a key role in establishing shelf life. In the case of chilled products, most products in the UK have a chilled shelf life between 1-10 days, with strict industry guidelines for those foods which have an elevated risk of *Listeria* or *Clostridium botulinum* in the case of vacuum and modified atmosphere packed foods. The Sustainable Shelf Life Extension (SUSSLE) project (2008-2018) provided insights used by the Chilled Food Association to create industry guidance for setting shelf life with respect to non-proteolytic *C. botulinum* for increasing shelf life and reducing waste and energy (8). For short shelf life products, it is best practice and feasible to conduct real-time shelf life tests. Manufacturers may also use challenge testing as a supplementary form of evidence for formulation resilience, such as the effect of sodium reduction. Other testing practices for consumer trials include rejection, discrimination and control testing. Building up historical data on raw materials (whether microflora or protein profiles and how that changes with seasons, as highlighted earlier) can help in cases where substitution, or reformulation, is needed. In these cases, accompanying discriminatory sensory tests are useful to establish changes to quality shelf life. Furthermore, decisions on whether to test at regular intervals (periodic sampling), or freeze samples at the point they need to be tested so they can be evaluated all together, have commercial implications such as the cost of running sensory panels, and panellists' availability.



For longer shelf life ambient products, while real-time tests are ideal, they can severely delay product launches so accelerated shelf life tests (ASLT) are a useful option, though limitations of this method must be considered when making conclusions. For an ASLT to yield reliable data, product systems are usually simple, the deterioration mechanisms must be known and usually exclude microbiological changes. It functions on the principle of the Arrhenius equation where kinetic factors are selected, and the product is aged under more extreme conditions to increase the rate of certain chemical reactions, such as discolouration upon exposure to light/oxygen or loss in sensory properties. ASLT must be supported by real-time shelf life tests and carried out under 2 or 3 different testing temperatures, to understand the temperature sensitivity and activation energy of the factors at play (9, 10). Using warm or high humidity chambers is useful to understand how a product might perform, though the use of this technology would depend on the type of food or drink product under investigation. The chambers can also be beneficial in preparing for export markets, where there are expected elevated temperatures which might not be part of the home market product history.



Validation

With shelf life design finalised, the microbiological safety must be proven before presenting samples for consumption. Sensory analysis is a key component of shelf life setting, with panels testing the aroma, taste, appearance, and texture of a product. When presenting samples to a panel for testing, minimising bias can be achieved by: presenting samples in varying orders to different panellists, randomising numbers, labelling uniformly, presenting equal quantities of samples taking care that the total amount does not provide more than 25% of their recommended intakes for that nutrient. Panels may be trained or untrained based on the testing requirements. For example, a detailed descriptive analysis would usually be carried out with a trained panel, however a simple triangle, duo-trio, or acceptability test may be carried out by non-trained personnel. Statistical tools may then be used to identify when consumers may accept or reject changes, and this information can be used to influence decisions. Throughout the process of setting shelf life, rigorous documentation of the testing and validation methodology is essential for compliance with food safety legislation. These documents should include shelf life test records, analytical results and decision making to provide evidence of due diligence and traceability.

Reassessment

Visualising shelf life as a living specification, not a fixed number allows a business' product to evolve with improvements to formulation, processing and potential changes to packaging and/or innovative packaging technologies. For products with variable raw materials, an ongoing verification programme would ensure that the shelf life set remains appropriate despite potential seasonal variations. Similarly, environmental and seasonal temperature variation can affect shelf life and therefore setting different shelf life durations for

seasonal production periods may be appropriate, or a 'safety buffer' may be utilised to accommodate uncertainties.

Furthermore, a consistent re-evaluation of shelf life would enable a business to be ready to respond to unprecedented situations such as the sunflower oil shortage in supermarkets caused by the Russia-Ukraine war. Some brands also had to modulate their process to align with supplies such that they swapped high oleic sunflower oil for a blend of rapeseed and sunflower oil, there may also be rapid increases in the costs of certain commodities such as cocoa, influencing the decisions of businesses. Another example relates to the sustainability footprint of a food/drink product, where businesses may choose to procure more locally. In any case where there are such changes, developers must understand the properties of their raw materials and the expected manner of spoilage in the final product e.g. lipid oxidation or microbial.



Outlook

Shelf life testing is complex and involves many decision variables. For a business to successfully set product shelf life and maintain standards, considerations should focus on category norms, industry guidance, hygiene, raw material standardisation, formulation resilience, and process standardisation. A combination of methods such as laboratory testing, challenge testing, modelling, and sensory evaluation are useful to understand and map the complex journey of a food or drink product's safety and quality over time in different seasons and storage environments. Overall, shelf life setting for food/drink products should be treated as a continuous improvement process.

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Further Reading

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