

Not Your Mentor's Shelf-Life Methods



J. F. CLEMMINGS, M. H. NOTTURNO, L. OCCHINO, AND M. PORTER
Merlin Development, Inc.
Plymouth, MN, U.S.A.

We all know how we are supposed to conduct effective product development: consumer-validated concepts, formulation, processing, consumer testing, optimization, and product quality shelf-life testing before product introduction.

We hear you snickering. When was the last time you followed the plan? How many of your products go to market before product quality shelf-life testing is complete or even conducted?

The unfortunate reality is that speed to market can trump conducting shelf-life testing. Sometimes testing is skipped because a formulation change seems relatively insignificant, but we all know an example of when that resulted in an unexpected product failure. Or, we start shelf-life testing with the best intentions, but urgent matters pull us away.

So, what's a scientist to do? Skip shelf-life testing? Never. However, there are some other methods that can be used to reduce the risk of quality failure: gathering data up front (consumer complaints, product comparisons, and processing and distribution information), understanding basic modes of failure, formulating with shelf life in mind, working with packaging and evaluating shelf life early on, and accelerating shelf-life testing when possible. Used together, these methods may buy us (and our product) time in the market while we complete traditional shelf-life testing.

- Today, many products go to market before shelf-life testing is complete. There are some methods that can help minimize the risk of product failure in the marketplace while buying time to complete shelf-life testing.
- Consumer complaints, product comparisons, and processing and distribution information can give insights into potential modes of failure and typical shelf-life time frames.
- It is vital to formulate with shelf life in mind, work with packaging early on, evaluate shelf life at the beginning, and perform accelerated shelf-life testing when possible.

Gathering Data

Consumer Complaints Are Not All Bad

So often, we never see consumer complaint data until there is a problem. But if your company has related food products, consumer complaint data is real-time market shelf-life information. It is an unmined field, useful if one focuses on rising trends, rather than just red flags, and if the age-related data can be separated out. Consumer complaint information can help identify areas of focus and potential modes of failure and help structure testing. For example, complaints of a cardboard-like flavor in a similar product indicate early oxidative rancidity as a mode of failure, suggesting the need for an antioxidant, chelator, or oxygen scavenger. Complaints of separation in a sauce or dressing indicate early emulsion failure, suggesting the need for improving the stabilization system. Reduced baked volume in current products suggests additional tolerance work is needed to formulate new products for baked volume robustness. A word of caution: Although consumer data can be useful, don't assume an issue doesn't exist just

because it hasn't shown up in complaint data.

Mine Existing Products for Clues

We can gain some insight into modes of failure and overall expected shelf life by examining and/or comparing shelf-life data of similar food systems as close in character to the new product as possible. For line extensions or to reverse engineer an existing product, this is relatively easy to do. Table I shows the shelf life data for various food systems.

However, for new products, it can be a bit more challenging, but still helpful. For example, a unique, coextruded shelf-stable snack would need to be compared to a variety of products that are similar in protein content, water activity, sugar composition, pH level, and other basic components. If the new product demonstrates some accelerated shelf-life issues not present in the target products, then the target product's ingredient declarations may hold clues for potential formulation modifications to extend shelf life.

Understanding Modes of Failure:

T, pH, A_w

A good understanding of the target distribution channel is important to classify the mode of failure, since a product's dominant failure mode can change at different temperature ranges (discussed more in the section on accelerated shelf-life testing below). Identifying the temperature(s) the product may see during distribution will help determine appropriate formulation, processing, packaging, and storage conditions. Some products such as ice cream and candy have very specialized distribution systems designed to address specific quality and shelf-life problems. For ice cream, product stress from retail to the home freezer can be the most critically

abusive part of the product's life. Also, assuming that a refrigerated product will only see temperatures of 35–45°F in distribution is wishful thinking at best.

Because mode of failure can be temperature dependant, processing must be taken into account. For example, heat treatment can reduce or eliminate microbial and enzymatic activity, but will not stop extremely heat-tolerant spoilage organisms or stop chemical changes from occurring in shelf

life. In fact, heat accelerates almost every degradative reaction, and once started, some of these reactions continue over a product's shelf life. To extend shelf life, it is important to use the least severe processing treatment, provided that microbial safety and desired product characteristics are obtained.

Mode of failure is also highly dependent on water activity. For low-water-activity foods, moisture absorption, lipid oxidation,

and flavor loss are the key drivers. Moisture absorption will result in a loss of crispness in cereals, cookies, and crackers. Moisture-barrier properties of packaging play an important role in these types of products. Higher water-activity products require some form of microbial preservation to achieve shelf-life goals.

Formulation—Build in Shelf Life

During the formulation phase of development, shelf-life issues can be considered alongside texture and flavor. Depending on the proposed storage conditions of the product and the desired shelf life, ingredients that are known to manage various aspects of product degradation can be incorporated into the formulation at the beginning of the process.

Microbial stability and safety is of course a critical concern. The tools to manage microbial growth in products are many and depend on product attributes and storage conditions. For example, the product might need ambient temperature stability for six months. A combination of water activity control, pH adjustment, and the addition of a preservative could be designed into the formula at the outset. Microbial challenge studies could be done early in the development cycle to determine the effectiveness of the microbial control elements.

Because lipid oxidation has a high relative reaction rate, the prevention of off-flavor development or rancidity should be addressed early in development. Lowering processing and storage temperatures is beneficial. Using antioxidants (natural and artificial) or encapsulating oxidation catalysts, such as those found in mineral supplements, may be needed. Additionally, working with the packaging design team is critical (see packaging section).

Flavor stability can depend on the flavor source and food matrix. Artificial flavors (and colors) often have a longer shelf life than their natural counterparts. The acid type and level in a food can change fruit-flavor profiles and stability. (Adding 0.1% of citric, malic, acetic, or tartaric acid can yield four different fruit-flavor profiles.) High-protein systems can sequester or mask flavors, and this will become more noticeable with time.

Color stability is a large concern since nonenzymatic browning (e.g., Maillard browning, caramelization, Vitamin C degradation) also has a high relative reaction rate. A food system needs to evaluate the following: source of proteins and sugars (especially basic amines and reducing sugars), pH and A_w (lower is better for both), heat of processing and storage (lower is better), catalysts (metals such as copper

Table I. Several examples of modes of failure

Product	Mode of Failure	Approximate Shelf Life
Ice cream/frozen desserts	Ice crystal growth—internal structure	6–12 months
	Freezer burn/surface ice formation	
	Gritty and grainy texture	
	Loss of flavor	
Frozen baked goods	Color changes (darkening)	3–6 months
	Loss of baked volume (due to loss of yeast viability and/or dough gas holding capacity)	
	Surface drying or freezer burn—more of a problem in retail where temperature cycling can drive surface drying	
	Dough color changes	
Refrigerated products	Microbial growth, causing increased acidity, lower pH, and or gas formation	1 week–4 months
	Off-flavor development	
	Syneresis and/or viscosity change	
	Color change	
Yogurt	Microbial growth, causing increased acidity and lower pH	1–2 months
	Increase in tart flavor	
	Off-flavor development	
	Loss of characterizing flavor	
Beverages	Syneresis and curdling	3 days–12 months ^b
	Color loss	
	Browning	
	Loss of flavor	
	Off-flavors, especially if fortified with vitamins, minerals, or nutraceuticals	
	Viscosity thickening ^a	
Fresh-baked products	Precipitation	1–7 days
	Drying	
	Loss of flavor and/or stale flavors	
Cereals	Staling, firming of structure	6–12 months
	Loss of flavor	
	Off-flavor development, including rancidity	
Cookies and crackers	Loss of crispness	6–12 months
	Lipid oxidation resulting in off-flavors	
	Loss/change in characterizing flavors	
	Color changes	
Snack chips	Oil oxidation, development of rancid off-flavors	2–3 months
	Loss of crispness	
Granola bars	Loss of crispness for crunchy bars	6–9 months
	Hardening of chewy bars	
	Binder separation (at higher temperatures)	
	Flavor loss or degradation	
	Off-flavor development	

^a High-protein beverages are pH dependent.

^b Shelf life depends on heat treatment (i.e., cold fill, hot fill, aseptic), distribution (i.e., refrigerated, ambient), packaging (i.e., paper board carton, bottle, brick pack), pH, fortification, etc.

and iron), and oxygen (although Maillard browning and caramelization reactions are anaerobic, oxygen is important since lipid and enzymatic oxidation makes hydroperoxides, which are catalysts for browning, as are Vitamin C degradation products.) Chelating agents and antioxidants may help (e.g., EDTA and citric acid).

Appropriate texture is another important concern. During formulation, ingredients can be included to help maintain the desired texture. For a baked good, it could be antistaling ingredients, such as emulsifiers and enzymes; water holding ingredients, such as sugars, gums, and starches; or tenderizers, such as lipids. Crisp foods need both low water activity and appropriate packaging (see packaging section). Dual-texture foods are always challenging. The key is balancing the water mobility between each fraction and using edible films or barriers when possible. Balancing water activity might mean $A_w = 0.4$, for a crisp cookie and its cream filling. Or, it could be a slightly higher A_w filling to purposefully soften its surrounding cake. An edible barrier could be something as simple as a solid fat coating between fractions, such as a layer of chocolate coating between a cone and ice cream.

Packaging Advantage—In the Beginning

Working with the packaging design team early on can define packaging criteria that will help maintain the desired product characteristics. For example, testing the product in packaging films with different water vapor transmission rates will show how water loss over time affects product texture and flavor. It may be that foil-lined packaging will help prevent loss of crispness more effectively than formulation changes. Or, if lipid oxidation is the failure mode, opaque packaging and/or nitrogen flushing may be a more effective preventative than formulation changes. Opaque packaging is also important to prevent color fading in some foods.

Testing Early—Evaluate as You Go

Routinely storing and evaluating product samples during development often clarifies modes of failure early in the development process. By monitoring the storage of the product during development, we can preemptively alter formulation to design a more stable system. For example, a product is formulated to prevent microbial growth by lowering both A_w and pH, but early samples show undesirable, nonenzymatic

browning. Found early enough, there is still time to change the types and levels of sugars and proteins, identify catalysts, and/or change processing parameters to prevent or lessen browning. Shelf-stable foods are sometimes high in sugars, which may crystallize out or harden with time. Caught early, there is still time to change the sugar system or add a humectant such as glycerin or sorbitol.

Every sensory evaluation is an opportunity to predict flavor shelf-life issues and respond with ways to mitigate or control changes. If flavor is fading, flavor level may be increased or a flavor enhancer, such as vanilla, could be added. If bitter flavors begin to develop, a flavor masker could be tested.

A note of caution: During development, selecting storage conditions can be challenging if the final packaging is unknown. If we store the product in a plastic bag, we may get oxidative rancidity that would not be seen if the final product package is foil lined. Conversely, if we store our product in plastic containers, but the final packaging doesn't provide good barrier properties, there may be stability issues that we fail to identify.

An ad appeared here in the print version of the journal.

Accelerated Shelf-Life Testing— Tried and True

Having or developing a validated accelerated shelf-life testing (ASLT) method is an important part of rapid product development. We are always looking to get an estimate of true shelf life in anywhere from one-tenth to one-fourth of the true shelf life. In order to achieve a validated ASLT result, testing against “normal” shelf-life conditions is required. Unfortunately, this is time consuming and often longer than the project timeline itself. In that case, it may be possible to find shelf-life information on a similar product and use that until the validation is completed.

Shelf-life validation develops a mathematical relationship between the rates of product deterioration at accelerated temperature to that at normal temperature for the various modes of failure. This relationship of rate of deterioration to rate of temperature change is frequently modeled in a Q_{10} form. The Q_{10} is the rate of change of an attribute (mode of failure) for every 10 degrees Celsius.

Table II shows a hypothetical product with a Q_{10} value of 2 (typical of some foods), and a 20°C (ambient) shelf life of 400 days (about a year). This could be a cereal, cracker, or other shelf-stable product. For a Q_{10} value of 2, the rate of deterioration doubles with every 10°C (18°F) increase in temperature. This example assumes one mode of failure over the range of temperatures (for example, rancidity). In this case, 100 days at 40°C (104°F) would be the accelerated test condition to predict if a product variation still meets or exceeds desired shelf life.

Caution: Accelerated testing data is only accurate if the mode of failure does not change over the temperature range tested. For example, some high-sugar bars and cookies undergo textural changes at 40°C (104°F) that do not occur at 30°C (86°F) or 20°C (68°F). In these cases, ASLT could be conducted at the intermediate temperature. Some protein-containing sweet goods will develop Maillard browning and off-flavors at 40°C (104°F) that do not occur at 30°C (86°F) or 20°C (68°F). In these cases, ASLT could be conducted rapidly at the higher temperature for texture only and somewhat slower at the intermediate temperature for flavor and color.

Table II. Hypothetical shelf life

Temperature (°C)	Temperature (°F)	Shelf life (days)
40	104	100
30	86	200
20	68	400

Ultimately, accelerated testing is accurate only if it has been validated against real world conditions and the failure mode is well understood.

Wrap Up

We all know that substitutes are rarely as good as the real thing. The methods outlined previously are no substitute for traditional shelf-life testing. But by gathering

data up front (consumer complaints, product comparisons, and processing and distribution information), understanding basic modes of failure, formulating with shelf life in mind, working with packaging and evaluating shelf early on, and accelerating shelf-life testing when possible, we may be able to buy ourselves (and our product) time in the market while we complete traditional shelf-life testing.



(Left to right) John F. Clemmings, Missy H. Notturmo, Marty Porter, and Lolly Occhino.

John F. Clemmings has 20+ years of experience in the food industry working for Pillsbury, Food Systems Design, and Merlin Development, Inc. He has an M.B.A. degree and a B.S. degree in chemical engineering from the University of Minnesota. He is a member of the Institute of Food Technologists and holds three U.S. patents. His technology experience includes frozen desserts; chemically leavened and yeast dough products; RTE canned soup; frozen meal kits; refrigerated, frozen, and shelf-stable sauces; low- and high-acid beverages; and nutritional products. He can be reached at jclemmings@merlindev.com.

Missy H. Notturmo has 17 years of experience in the food industry working for Frito Lay, Pillsbury, and Merlin Development, Inc. She has an M.S. degree in food science from the University of Wisconsin and a B.S. degree in food technology from Texas Tech University. Her technology experience includes nutritional beverages and nutritionally fortified baked goods; extended shelf-stable baked goods; chemically leavened and yeast dough products; refrigerated dough; snack foods; cookies; fillings; frozen baked goods, vegetables, and sauces; fresh and dried vegetables; refrigerated egg products and dips; gluten-free foods; and strategic cost-savings analysis. She can be reached at mnotturmo@merlindev.com.

Lolly Occhino has 20+ years of experience in the food industry working for Lipton, Pillsbury, and Merlin Development, Inc. She has B.S. and M.S. degrees in food science from the Universities of Wisconsin and Minnesota, respectively. Technology experience includes condiments, salad dressings, fruit snacks, extruded products, confectionary, hot fill and retort products, ethnic foods, flavor optimization, bakery dry mixes, cereal bars, beverages, frostings, hot cereal, shelf-stable baked goods, microwave foods, ingredient applications, sensory evaluations, shelf-life assessments, whole grain foods, and school lunch program foods. She can be reached at locchino@merlindev.com.

Marty Porter has 18 years of experience in the food industry working for Merlin Development, Inc. She has a B.S. degree in medical technology and is a member of AACC Intl. Her technology experience includes yeast-leavened breads; chemically leavened baked goods; cereal products; granola, cereal, and nutrition bars; frostings; extended shelf-stable foods; frozen sauces; objective texture analysis; digital imaging applications; quality assurance test design; fast food operations/procedures; and prototyping. Porter can be reached at mporter@merlindev.com.