Executive Summary

- Managing moisture in frozen-product formulations.
- Minimizing freeze/thaw degradation in frozen products.
- Using gums and starches to increase frozen-product stability.

Stabilizing Influences for Frozen Products

By R.J. Foster
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Early advances in frozen-food technology likely focused on finding enough snow to cover an entire slab of bronto-ribs.

Fast-forward to 1953. Clarence Birdseye's research in the realm of liquid freezing technology leads to the introduction of the "TV dinner"–a complete meal right out of the freezer that would redefine the term "convenience" for American consumers.

"We have seen studies that say the global market for frozen food could potentially be worth $226.5 billion by the year 2015," says Maureen Akins, applications manager, TIC Gums, White Marsh, MD. "For frozen-food formulators and packagers, converting repeat business from consumers relies on the quality of the new or reformulated products they sell. Incorporating plans for stability and texture early in the process is the best way for them to proceed as it allows better results, earlier in the process than not."

Ch-ch-ch-ch-changes

Water expands when frozen, increasing its volume by 9%, forming crystals that will vary in size and number based on the conditions of their formation. Slower freezing rates yield fewer, larger crystals. Rapid freezing yields greater numbers of smaller crystals. Small crystals are, however, susceptible to even minor fluctuations in temperature, often melting into free water that then freezes onto other ice crystals, resulting in growth and expansion that can cause both mechanical and chemical effects.

Water within flexible cellular structures throughout a food matrix expands as it freezes, filling once-open spaces with ice. Upon thawing, the water is released and observed by the consumer as syneresis. Rigid structures like those of plant or vegetable tissues are more likely to simply break under the forces of the expanding ice crystals. In this case, visual and textural effects are observed.

Emulsions can be devastated when ice crystals grow within and rupture water droplets dispersed through the fat phase. The result, observed upon thawing, is a broken emulsion. Emulsion stability can also be affected by increases in ionic strength of solutes present in water that has not yet been frozen. Changes in the ionic character of food can permanently destabilize proteins and cause solute crystallization and/or precipitation that will affect finished-product taste and texture. Increases in concentration of certain solutes will also make the product more reactive, i.e., more susceptible to undesirable oxidative changes in taste and color.

Photo: TIC Gums

Products can continue to undergo changes during frozen storage and transportation because, technically speaking, they are not completely frozen. Pure water freezes at 0° C. Soluble materials such as salts or sugars depress the freezing point by almost 2° C for every added mole (one molecular weight expressed in grams). Food products are complex, containing far more than a mole or two of solutes such as salts, sugars, proteins or fiber. These will affect the temperature at which a food system is devoid of free moisture—the eutectic point. And, unfortunately, most foods' eutectic points are lower than commercial freezing processes can achieve: around -50° C for meats, -55° C for ice cream, and -70° C for bread.

Despite being "frozen," moisture is still moving. Temperature gradients that arise from fluctuations in temperature can drive water toward cooler temperatures typically found at the surface of a product. While temperature gradients may reverse, water that has found space to collect in product voids and packaging gaps will not return.

Poor or inappropriate packaging can allow moisture to evaporate from the surface into the environment, causing dehydration, known as freezer-burn.

When freezing point is ambiguous, and eutectic point is not feasible, some developers turn to glass-transition temperature, or Tg. This is the temperature at which the product enters a "glassy" state, becoming a noncrystalline solid. When products are stored below the Tg, viscosity of unfrozen liquid is so great that diffusion-dependent effects such as moisture migration, ice recrystallization and surface ice formation are practically halted. Chemical reactions are also brought to a standstill as reactants are no longer able to diffuse into the unfrozen liquid.

Like freezing point, Tg will change with the composition of the product. Low-molecular-weight solutes like sugar will lower Tg. This is an important consideration when formulating. Frozen desserts with high-molecular-weight sweeteners will be more firm than those incorporating low-molecular-weight ones. Using high-fructose corn syrup will yield a spoonable texture at frozen temperature. The resulting depression of Tg can, however, allow ice-crystal growth that will, through storage, ruin the product's texture.

Super starches

Processors are continually discovering new means of addressing problems before they arise. Rapid freezing, proper packaging and consistent temperatures through transport and storage all help minimize freeze/thaw degradation. Advances in processing technology are matched, though, by a growing number of opportunities to utilize functional ingredients to enhance stability, improve quality and create new offerings altogether.

Starch is one of the most commonly utilized ingredients for improving freeze/thaw stability. With products able to hold upwards of 20 times their weight in water, starches provide cost-effective options for managing moisture while offering opportunities to enhance or modify texture. Starches come in many varieties, though, and no one type is right for every application.

When considering native starches, the highly branched amylopectin in waxy maize makes it a better choice for freeze/thaw stability than corn, potato and tapioca, which are predominantly straight-chain amylose. The branching helps hinder retrogradation, the reassociation of starch chains that leads to syneresis. Native, unmodified starches are not, however, immune to freeze/thaw issues. Concentration effects during freezing can result in undesirable cross linkages that can keep the starch from rehydrating during thawing. Starch granules can also suffer physical damage from ice-crystal growth.

A starch's freeze/thaw stability can be improved by substitution, creating crosslinks through acetylation or hydroxypropylation. The latter is better for freeze/thaw stability as hydroxypropyl groups can be added at higher levels, creating more branching and more resistance to reassociation. Hydroxypropylation also creates a more open structure that increases viscosity.

Substitution allows processors to take advantage of textural effects of other starch types. Waxy maize delivers high viscosity and gel clarity, and good processing tolerance. A substituted dent starch, on the other hand, can offer increased syneresis prevention with a short texture and potential gelling effects. Starches based on tapioca offer functionality with very bland taste, a distinct benefit in products with delicate flavor profiles such as frozen dairy desserts.

Other specialized starch types prevent issues in other ways. Low-pasting-temperature starches added to sauces or gravies can absorb moisture released during thawing, as well as additional water lost from other ingredients during reheating. Instant starches hydrate without heat, allowing them to control moisture immediately, improving batter viscosity and aeration in production, and maintaining moist mouthfeel and desirable crumb texture through shelf life.

Rule of gum

Gums provide additional options for improving stability in various applications. "Gum systems work exceptionally well in harsh processing environments where wide temperature fluctuations can change the overall stability and textural characteristics of the finished product," says Akins. "We look for the right combination of gums that provide the best solution in terms of texture, stabilization and cost of use."

There is definitely an increase in demand for stabilizers for all kinds of frozen products, notes Janae Kuc, senior laboratory technician, Gum Technology Corporation, Tuscon, AZ. "Ice creams and frozen novelty stabilizers are pretty popular, especially to help with shelf life, ice-crystal control, and melting properties. A blend of tara gum and guar gum works well for this application," she says.

Sauces present unique challenges to developers. "For sauces, work to include the proper viscosifying and emulsifying hydrocolloids. The best formulations will provide viscosity and textural attributes to the sauce, suspend particulates, and prevent separation of oil and water," Akins says. "Products like guar, gum arabic, and xanthan can aid with stability and contribute to a better texture."

Combinations of gums and starches can also present opportunities for developers. "In frozen sauces," Kuc suggests, "you can use a combination of starch, guar and xanthan to help improve the freeze/thaw stability. If the product has a high oil or fat content, you can combine these with some gum arabic, fenugreek gum or propylene glycol alginate to improve the emulsion stability."

Kuc notes the growing interest in stabilizers for frozen baked goods. "We have been working with a lot of customers on stabilizing icings and toppings, as well as on frozen dough, and frozen cakes and cheesecakes," she says. "A blend of modified food starch, microcrystalline cellulose and carboxymethyl cellulose (CMC) works well in frosting and icing applications to create viscosity, hold aeration and provide texture with a smooth mouthfeel. On the frozen side, it improves freeze/thaw stability and prevents sugar bloom."

As with starches, gums offer benefits in the realm of bread products. "For bread," says Akins, "the challenge is to preserve flexibility (moisture control), which can be accomplished with combinations of xanthan, guar or CMC." She suggests usage levels for baked goods and dough applications are up to 16 oz. per 100 lbs. of flour.

Increased demand for guar in nonfood industries has, according to Akins, caused reduced supplies that could result in historically high prices for guar in 2012. "A newly developed blend of cellulose and xanthan gum can replace guar gum in bakery mixes for bagels, cake, muffins, etc., while maintaining key attributes like moisture retention and crumb structure over the course of the product's shelf life. Typical usage levels range from 2 oz. to 5 oz. per 100 lbs. of flour."

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