

Shortening Systems: Fats, Oils, and Surface-Active Agents—Present and Future¹

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ABSTRACT

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Shortening systems are undergoing an evolution in both chemically leavened and yeast-raised baked foods. New types of shortenings are being used at levels quite different from those of the past. In yeast-raised baked foods, higher levels of surface-active agents increase the shelf life of the baked product and impart a dough conditioning action that results in improved product quality and uniformity. Surface-active agents permit the baker to use vegetable oils without concern for the solids index. In chemically leavened baked foods, shortening level and the polymorphic

form of the solid shortening crystals have historically played a critical role in the development of cake quality, especially in batter aeration. Newer developments in the use of surface-active agents have largely obviated concern for crystal polymorphism and have allowed the use of new shortening types at reduced levels. Current and anticipated changes in shortening systems are discussed, with particular emphasis on the role of surface-active agents in these changes.

Until recently shortening used in baked food required a critical level of fat solids, and the crystalline form of these solids was extremely important in imparting desirable qualities to the baked food. Recent studies, however, have demonstrated that, with the proper use of surfactants, concern over the solids indices and crystal polymorphism of shortening used in both yeast-raised and chemically leavened baked foods is unnecessary. The baking industry is currently involved in a changeover to the use in both bread and cake of vegetable oils that contain essentially no solid fat and that can be used at lower levels for greater economy.

HISTORICAL BACKGROUND

Until recently lard was the fat most widely used as shortening in the U.S. baking industry. It was eminently suitable for use in conventionally processed bread and was widely used as a shortening in cake and other chemically leavened baked foods after suitable hydrogenation and compounding to obtain the necessary solids and crystallinity. However, U.S. Department of Commerce statistics (1972, 1977) indicate that the use of lard as a shortening in the United States has been dropping rapidly (Table I). From 1950 to 1975 its use was reduced by more than half. During 1978, concurrent with the introduction of new labeling regulations requiring the source of shortening to be disclosed on the label, bakers responsible for an estimated 80% or more of the wholesale bread production in the United States converted to the use of vegetable oil.

Lard had been the shortening of choice in breadmaking because it possesses several unique characteristics compared to other fats. It used to be in plentiful supply—readily available from local hog abattoirs at low cost. Because of its low solids content at dough mixing temperatures, it disperses thoroughly in the dough, imparting excellent shortening characteristics to the bread or other baked food. Tallow, by comparison, is a much firmer fat because of its higher solids index at dough mixing temperature and, unless specifically modified, is poorly dispersible in doughs, imparting a reduced shortening effect.

The open kettle lard of many years ago was rendered at 230–240° F, which cooked the residual meaty tissues and imparted to the lard a flavor that some bread bakers considered desirable. Little, if any, of such lard is produced today, lard being wet-rendered under vacuum, filtered, and steam stripped to provide a completely bland product known as “prime steam lard” (Swern 1964).

Lard, however, was not a primary product, but rather a by-product of the pork-processing industry. With the growth of the

commercial baking industry in the late 19th century, chronic shortages of lard developed when the demand for pork products was low. The search for a substitute for lard led to the development of the vegetable oil industry. The first compound shortenings were blends of cottonseed oil and a hard stock such as oleostearine, which was pressed from tallow. An 80:20 blend of oil/oleostearine provided a plasticity and dispersibility similar to that of lard.

PRODUCTION AND COMPOSITION OF SHORTENING

Hydrogenation of oils to increase the solids content of shortening was commercially introduced about 1910. Thereafter, vegetable oil could be converted to shortening with the desired solids content in three ways: 1) by blending the oil with a solid stearine fraction derived by pressing from an animal or vegetable source, 2) by fully hydrogenating a fraction of the oil to produce a stearinlike hard stock and blending this with oil, and 3) by partially hydrogenating all of the oil to produce sufficient solids *in situ*.

The solids content at dough mixing temperature of lard or any other shortening was known to be important. Baker and Mize (1942) demonstrated that shortening with a low solids content exerted a deleterious effect on bread quality. They suggested that solid fats, when present in sufficient quantity, improved the gas retention of the doughs by plugging voids in cell walls. Baldwin et al (1963, 1965) observed changes occurring in dough structure while dough was being baked under a microscope. They confirmed the beneficial effects of 10–12% crystalline fat and appeared to confirm the postulate of Baker and Mize (1942) that solid fats fill small voids in the gluten film.

Baldwin et al (1963) proposed the desirability of a β' -crystal structure in bread shortening on the basis that added cottonseed and tallow flakes, which tend to promote the development of such crystal structures, provided better grain and volume than did an equal quantity of soya oil and lard flakes, which tend to promote the formation of larger β -crystals.

The practical baker knew that the shortening should have a “slip

TABLE I
Food Use of Fats and Oils^a

Fat or Oil	Amount (millions of lb) Consumed in			
	1950	1960	1970	1975
Butter	1,327	1,112	890	815
Lard	1,906	1,361	940	616
Shortening	1,705	2,302	3,556	3,666
Margarine	764	1,367	1,787	1,908
Other fats and oils	1,314	2,094	3,635	4,299
Total	7,016	8,241	10,808	11,304

^aU.S. Department of Commerce, Bureau of the Census (1972, 1977).

¹Portions presented at a symposium, Theory and Application of Lipid-Related Materials in Breadmaking: Today and Tomorrow (Not Yesterday), at the 64th Annual Meeting, Washington, DC, October 1979.

point" or capillary melting point about 8°F higher than the temperature at which the dough was discharged from the mixer. Lard or other bread shortening was compounded to provide a melting point of 94–96°F, ideal for dough-out temperatures of 86°F. With the introduction in the early 1960s of continuous high shear dough mixers, dough-out temperatures of 104–106°F became common, requiring shortening slip points of 112–115°F. This was usually obtained by the baker himself by melting hard stock, known as stearine "flakes" into the lard in sufficient quantity to obtain the required solids content. Bread shortenings generally possess 20–35% solids at room temperature and 10–15% solids at dough-out temperatures.

In preparing a plastic or even a fluid compound shortening, great care must be exercised not only to provide the proper level of solids but to develop the solids into the proper crystalline structure. Just as Baldwin et al (1963) found that optimum grain and volume in bread were obtained with shortening containing crystalline fat in the fine (1- μ m needles) β' configuration, so Hoerr and Ziemba

(1965) found that such shortenings produce cakes of excellent volume and fine texture. Such shortenings are characterized by a creamy plastic texture, excellent dispersibility in dough or batter, and a low melting point, producing a finely divided gas phase as a result of solidification. If the shortening is unstable and undergoes polymorphic monotropic transformation to the large β crystals (20–50 μ m rods), the shortening will be coarse and grainy with poor dispersibility, resulting in poor batter aeration. Such shortenings are, however, desirable for producing flakiness in pie crusts and Danish pastries (Mattil 1959).

All naturally occurring fats and oils are mixed triglycerides. Simple ones with a limited number of triglycerides, such as lard, tend to the coarse β structure unless molecularly rearranged during refining, an added and costly step. Fats with a more complex mixture of triglycerides, such as partially hydrogenated soybean oil, tend to be naturally more stable, retaining the fine β' structure.

Shortening production may therefore contain several steps besides refining. These include blending, hydrogenation, interesterification, glycerolysis, fractionation, solidification, and tempering to obtain the desired crystal polymorph.

TABLE II
Description of Typical Oils Used in Baked Products^a

Use	Antioxidant	Iodine Value	Stability ^b (hr)	Oil Storage (days)
Fresh bread and rolls	none	125–135	15+	30
Baked food stored 60 days or less (eg, croutons)	yes	125–135	30+	30–90
Baked food stored 90 days or more	yes	108–114	50+	90+ (warm climate)

^a Personal communication, Dr. Simon S. Jackel, Quality Bakers of America.

^b By active oxygen method, CD12-57 (AOAC 1964).

SHORTENING EMULSIFIERS

With the introduction of monoglycerides in cake shortening about 1930, the functional value of the shortening became less dependent on the amount and crystalline form of solid triglycerides. The monoglycerides and diglycerides were produced in the shortening in situ by glycerolysis (interesterification with excess glycerin). Such superglycerinated shortenings contained about 8% monoester and were referred to generically as "hi-ratio" shortenings because they permitted the use of higher ratios of sugar to flour (eg, 130:100). Wooten et al (1967) demonstrated that the surfactant system in cakes protects the foaming ability of the protein against the antifoam properties of fat and oil, thus permitting the use of higher levels of tenderizing ingredients without loss of volume.

The reduced need for shortening solids with the use of surfactants led eventually to the introduction of fluid shortenings for use in both yeast-raised and chemically leavened baked foods. These shortenings contained a minimum level of solids, typically 25–30%, in the form of either triglycerides or surfactants. Ellinger (1962) determined that a fluid cake shortening should contain at least 10% fat or emulsifier solids for acceptable functionality. A number of commercial fluid bread and cake shortenings based on

TABLE III
Specifications of Baker's Shortening Oil (Soybean)

Quality ^a	Specification
Iodine value	108–110
Stability ^b	
Bread only	15 hr minimum
Croutons/bread stuffing	25 hr minimum, preferably 50 hr
Color	1.5 Red maximum, 15 Yellow maximum
Free fatty acids	0.05% maximum
Free glycerine	1.5% maximum
Flavor and odor	Bland
Antioxidants	As required
Methyl silicone	None
Cold test (hr)	5.5 minimum
Linolenic acid	0.0%
Smoke point	440°F minimum
Peroxide value	0.5 maximum

^a By methods of the American Oil Chemists' Society (1964).

^b Active oxygen method.

TABLE IV
Effect of Reduced Oil Levels on Crumb Softness of Bread^a

Type of fat	Level (%) ^b	Percent Mono/Poly 60 Blend ^c	Dough Handling	Increased Volume of 1-lb Loaf (cc)	Average Softness Index ^d (3–6 days)	Grain
Lard	3	...	Good	...	1.00	Good
	3	1.0	Good	19	0.81	Good
Soya oil	3	1.0	Good	32	0.80	Good
	2	1.0	Good	58	0.76	Good

^a Adapted from Hartnett and Thalheimer (1979a).

^b Of flour weight (14% moisture content).

^c 50% active.

^d Index = compression (g) of test crumb/compression (g) of control crumb. Lower values indicate softer crumb.

TABLE V
Effect of Shortening Solids vs Conditioner in Bread^a

Type of Shortening ^b	Mono/Poly 60 Blend (%) ^c	Proof Time (min)	Average Volume Increase of 1-lb Loaf (cc)	Average Softness Index (7 days)	Grain
Lard	...	65	...	1.00	Good
	0.5	64	136	0.78	Good
Soya oil	0.5	64	225	0.72	Good
	...	65	73	0.94	Good
Cottonseed oil	0.5	63	148	0.70	Good

^a Adapted from Hartnett and Thalheimer (1979a).

^b 3% of flour weight (14% moisture content).

^c 100% active basis.

TABLE VI
Amount of Fat Needed in Cake Formulations^a

Cake	Plastic Shortening (%) ^b	Oil (%) ^b	Percent Reduction
115% White	21.0	14.0	33
130% Yellow or devil's food	41.0	17.0	60

^a Adapted from Hartnett and Thalheimer (1979b).

^b Of flour weight (14% moisture content).

TABLE VII
Use of Oil in 115% White Cakes^{a,b}

Type of Fat	Type of Emulsifier/Percent ^a	Fat (%) ^c	Specific Gravity	Viscosity (mcps) ^d	Volume Increase Over Control (cc)	Softness Index ^c (days)			
						1	5	10	Grain
Plastic	...	21.0	1.00	31.8	...	1.00	1.33	1.61	Good
Oil	Commercial hydrate/3	21.0	0.94	32.2	110	0.86	1.13	1.40	Good
	Hydrated blend ^f /5	14.0	0.89	30.0	65	0.93	1.00	1.26	Good

^aAdapted from Hartnett and Thalheimer (1979b).

^b8-in. layers.

^cOf flour weight.

^dBrookfield Viscometer RVT, No. 6 spindle (cps × 1,000).

^eLower index indicates softer crumb.

^fPolysorbate 60 (8%), sodium stearoyl-2-lactylate (4.0%), and mono and diglycerides, 36%.

vegetable oil have been developed; all of these contain some solids, usually about 20–30% suspended triglycerides and surfactant.

Bayfield and Young (1963, 1964) evaluated the need for solids in liquid shortening used in bread and determined that 5% solids were required when the dough was proofed at 100° F and 10% solids when the proofing temperature was 120° F.

The first reference to a clear liquid cake shortening was that of Moncrieff et al in 1965.² However, dissolved solids in this shortening tended to recrystallize and separate permanently when subjected to wide fluctuations in temperature.

The first references to a stable clear liquid cake shortening were those of MacDonald and Lensack (1967) and Lensack (1969), in which they cited the use of a high purity propylene glycol monostearate at levels of up to 12% in vegetable oil. Excellent results were obtained with this combination in a variety of cake formulations. The clear liquid blend remained stable even when cycled at temperatures between 40 and 110° F. Although it gelled at the lower temperature, the gel dissolved when the blend returned to 68–72° F.

SURFACE-ACTIVE DOUGH CONDITIONERS

During the 1950s and 1960s, a number of surfactants were found to impart improved mixing and machining characteristics to doughs and to improve the quality of bread baked from such doughs. Among these surfactants were calcium and sodium stearoyl-2-lactylate, polysorbate 60 (ethoxylated sorbitan monostearate), ethoxylated glyceryl monostearate, succinylated monoglycerides, stearoyl monoglyceridyl citrate, and sodium stearoyl fumarate.

The characteristics imparted to the dough and bread by these surfactants, currently referred to as “dough conditioners,” are improved gas retention, greater dough strength and mixing tolerance, faster rate of proof, better oven spring, improved rate of hydration and total absorption, more extensible doughs, greater loaf volume, improved symmetry, closer grain, and brighter crumb.

The functional improvements imparted by the surface-active dough conditioners not only duplicated all of the characteristics imparted by shortening solids but supplied a number that were unique (improved mixing tolerance, water absorbance, and extensibility and a longer shelf life).

SURFACTANTS AND OILS

That proper use of a surface-active dough conditioner obviated the need for concern for the level and crystalline form of solids in bread shortening was proven when the first commercial plant trials took place in 1974 using polysorbate 60. These results were corroborated by extensive laboratory and pilot plant evaluations. Results obtained with the use of vegetable oil in conjunction with the conditioning surfactant have been such that an estimated 80–90% of the wholesale bread and other yeast-raised baked foods produced in 1979 in the United States contained vegetable oil with

²J. Moncrieff, J. V. Luck, and C. W. Hoerr. 1965. Development of clear fluid shortenings. 6th Annual Symposium, Central States Section, AACC, St. Louis, MO.

TABLE VIII
Use of Propylene Glycol Monostearate (PGMS)-Type 2180 Emulsifier in 130% Yellow Cakes^a

Emulsifier	Emulsifier (%) ^b	Batter Gravity (cc/g)	Volume Increase Over Control (cc)	Grain
	10.0	0.82	269	Good, smooth crust
	12.0	0.78	254	Sl. ^c tender, sl. open
	14.0	0.74	271	Sl. tender, sl. open
Soya oil	...	1.03	...	Greasy, grainy
Fluid shortening	...	0.93	141	Sl. tender, sl. open, smooth crust

^aAdapted from Hartnett and Thalheimer (1979b).

^bOf oil weight.

^cSl. = slightly.

no significant amount of solids. The oil may or may not be winterized for clarity at low temperatures. Unwinterized oils often develop a haze at cool temperatures, eg, 40–50° F, due to the presence of a small amount of triglycerides, which solidify at this temperature. If desired, these solids can be removed by the refiner by centrifugation or filtration.

The oil may be stabilized to any reasonable degree of oxidative stability. This can be done by addition of antioxidants, light hydrogenation to convert unstable polyunsaturated fatty acids to more stable ones, or a combination of both approaches.

The required degree of oxidative stability will vary with the surface area per unit weight as well as the shelf life desired for the baked food.

Some suggested oxidative stabilities, as measured by the active oxygen method (AOAC 1964) are given in Table II. Suggested specifications for a good quality soybean oil suitable for bakery purposes is given in Table III.

Currently soybean oil is the most widely used oil, simply because of its relatively low cost. However, any edible oil of animal or vegetable origin may be used if it possesses the required flavor and oxidative stability. Cottonseed, peanut, and palm oil have been used but generally are more expensive than soy oil. Presently, rape and sunflower seed oils are taking on more economic importance in Canada and the United States and, when properly refined, make excellent shortenings.

Hartnett and Thalheimer (1979a, 1979b) have studied the use of vegetable oil in conjunction with various surfactants in bread, sweet goods, and cakes. Using carefully controlled laboratory studies, Hartnett and Thalheimer (1979a) confirmed plant experience demonstrating that, in comparison with lard containing about 30% solids, oil provided at least equivalent shortening results with a one-third reduction in usage level. They also found that the reduced level of oil, used in conjunction with the proper type and level of surfactant, eliminated the coarse texture and poor loaf volume obtained with oil, as reported by other investigators (Baker and Mize 1942). In addition, improved water absorption and

slower rate of crumb firming were observed (Tables IV and V).

Hartnett and Thalheimer (1979b) found that, as for bread, excellent results could be obtained with vegetable oil and a proper system of surface-active agents in yeast-raised sweet goods and cake. For yeast-raised sweet goods, a blend of polysorbate 60 and monoglycerides gave excellent results. For cake, shortening levels could be reduced 50–60% when oil and surfactant were substituted for plastic shortening (Table VI). Best results were obtained with a blend of polysorbate 60, sodium stearyl-2-lactylate, and monoglycerides (Table VII). Hartnett and Thalheimer (1979b) also confirmed the excellent results obtained by MacDonald and Lensack (1967) with oil and high purity propylene glycol monostearate (Table VIII).

SHORTENING SYSTEMS OF THE FUTURE

The bread-producing segment of the baking industry has already made the changeover from plastic shortening to vegetable oil. Data on the use of surfactants with oil in cakes have only been available in recent months; however, initial successes indicate that the changeover in this segment of the industry will be accomplished rapidly and completely.

The use of oil offers too many advantages to be ignored. Lower usage levels offer significant reductions in cost. Vegetable oil, polyunsaturated and free of cholesterol, appeals to the nutrition-conscious consumer.

Oil can be transported, stored, and pumped throughout the plant without the need for heating or sophisticated agitation equipment, with concurrent energy savings. It readily blends cold into powders, plastic doughs, or fluid batters.

Concern is not needed about critical solid-liquid ratios or precise polymorphic triglyceride structure. The oil requires none, and the surfactants conform to rigid compositional specifications. Purchasing departments prefer to deal in vegetable oils because they can be contracted for on a long-term basis at a time thought desirable by the astute buyer, whereas animal fats are usually purchased on a monthly basis.

Vegetable oil used in conjunction with the proper surfactant system appears to be the shortening of today and of the foreseeable future.

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