Chapter 9
Applications of Emulsifiers in Baked Foods

Frank Orthoefer

9.1 Introduction

Emulsifiers are multifunctional ingredients when used in bakery products. The three major functions are (1) to assist in blending and emulsification of ingredients, (2) enhance the properties of the shortening, and (3) beneficially interact with the components of the flour and other ingredients in the mix. Some of the specific functions are uniquely described as creaming, dough conditioning or crumb softening. This chapter discusses the activity and functional role of emulsifiers in baked products.

9.2 History of Bakery Emulsifiers

The development of emulsifiers for bakery products parallel the development of shortenings. The term "shortening" was initially used to refer to the fats used to "shorten" or tenderize baked foods. The composition of the shortening has progressed from natural fats to blends of oils, hydrogenated fats and hard fats as well as trait modified oils (Orthoefer, 2006a). Shortenings, once used for blends intended only for baked products, is now used to describe frying oils or almost any fat or oil used in food preparation. Shortenings intended for bakery products, however, may include additives such as emulsifiers, antioxidants, antifoam, and metal scavengers. Bakery shortenings may be the tenderizer as well as the ingredient that affects structure, stability, flavor, storage stability, eating characteristics and eye appeal. Many of the functional effects are due to, or are enhanced by, the emulsifier added as a component of the shortening.

Historically, animal fats were used for bakery products because of their natural plasticity and flavor (O'Brien, 1996). Lard was the preferred animal fat because of its pleasing flavor. With the excess of cottonseeds and cottonseed oil in the market, vegetable shortenings were developed by the cottonseed industry early in the twentieth century. Initially, cottonseed oil was blended with lard as a "lard compound" or simply "*compound shortening*." Hydrogenation was invented in 1910. This allowed the production of vegetable based substitutes for semi sold

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(plastic) animal fats and permitted the development of products with improved functional properties.

Along with the process to modify the melting properties of fats or oils (hydrogenation) came improved methods for processing the oil including refining, bleaching, and deodorization. The fully processed products possessed improved oxidative stability, uniformity and enhanced performance. Knowledge of lipid chemistry led to improvement in alcoholysis, esterification, interesterification, and isomerization. These advances in lipid chemistry led to new emulsifiers and improved shortening formulations. High ratio shortening was introduced around 1933. These shortenings contained mono- and diglycerides. The emulsifiers produced finer dispersions of fat particles in the dough giving strengthened cake batters. Stronger cake betters permitted increased water and sugar addition resulting in sweeter tasting, more tender cakes. The high-ratio shortenings possessed excellent creaming properties. Moist, high volume, fine-grained, even-textured cakes were produced. Icings were also improved (Hartnett, 1977).

Emulsifier development also advanced in the 1930s (Stauffer, 1996). Specialty shortenings were formulated. Commercial layer cakes, pound cakes, cake mixes, crème fillings, icing, whipped toppings, bread and sweet dough shortenings were created. This development of specialty emulsifiers resulted in improvements in processing and improved product performance for the retail, food service and food processing industries. In addition to the traditional plastic shortenings, liquid shortenings, fluid shortenings, and powdered products were produced (O'brien, 1995). All these products involved formulations with emulsifiers.

9.3 Definition of Emulsifiers

Emulsifiers are surface active agents that promote the formation and stabilization of an emulsion. A surfactant is also a surface active agent. The terms emulsifiers and emulsifying agent, surfactant and surface active agent are synonymous and used interchangeably in the literature. The terms "emulsifier" and "emulsifying agents" are, strictly speaking, chemicals or compounds capable of promoting emulsions or stabilization of emulsions by their effect on interfacial tension. Surfactants for foods may include not only emulsifiers but also compounds with other functions such as protein or starch interaction.

The roles of the emulsifier and of the shortening are intimately bound in bakery products. Generally, the food emulsifiers for bakery products supplement and improve the functionality of a properly developed shortening. Emulsifiers act as lubricants, emulsify oil or fat in batters, build structure, aerate, improve eating quality, extend shelf life, modify crystallization, prevent sticking, and retain moisture. A list of emulsifiers used in shortening is given in Table 9.1. The selection, and addition of an emulsifier to a shortening base may significantly change the application of the shortening (Table 9.2).

Table 9.1 Emulsifiers used in shortenings

Mono- and diglycerides	Sorbitan monostearate
Lecithin	Polysorbate 60
Lactylated monoglyceride	Polyglycerol esters
Calcium stearoyl lactylate	Succinylated monoglycerides
Sodium stearoyl lactylate	Sodium stearoyl fumarate
Propylene glycol monoesters	Sucrose esters
Diacetyl tartaric esters of monoglycerides	Stearoyl lactylate
Ethoxylated monoglycerides	–

Table 9.2 Examples of nonemulsified and emulsified shortenings

Non-emulsified	Emulsified
All-purpose	Cake and icing
Puff pastry	Household
Pie crust	Filling
Cookie	Cake mix
Danish roll-in	Yeast raised
Donut fry	Specialty cake

9.4 Emulsifier Function in Baked Goods

Baked goods without emulsifiers have been described as tough, dry, stale, leathery, or tasteless (Brandt, 1996). Current processing, distribution and storage of baked goods requires the use of additives that maintain quality and freshness (Orthoefer, 2006b). Fewer bakeries, longer distribution, and extra time before consumption requires longer shelf life of finished baked goods.

Emulsifiers are commonly used in many food products. These supplementary materials or food additives are used to

1. Compensate for variations in raw materials
2. Guarantee constant quality
3. Produce alternative products
4. Preserve freshness and eating properties
5. Facilitate processing (Schuster and Adams, 1984).

Emulsifiers promote the emulsification of oil in water. This is found for bakery emulsifiers. However, emulsification is often of secondary importance. Starch complexing, protein strengthening, and aeration may be the primary function. Fat sparing effects are also of importance.

The interaction between protein, carbohydrates, and lipids is significant for processing of wheat flour. “The flour itself exhibits interaction among components even in flour/water doughs. Starch is the major flour component followed by protein.”

The interactions between emulsifiers and flour components are multifaceted and account for the improved functionality and performance of baked products.

The use of surfactants in bakery products is regulated in most countries. The European Economic Community (EEC) number and U.S. FDA Code of Federal Regulations (21 CFR) for the most common food emulsifiers are shown in Table 9.3.

Wheat Flour	Percent
Starch	70.0–75.0
Protein	11.5–12.5
Pentosan	2.0–2.5
Lipid	1.0–1.5
Crude fiber	0.2
Ash	0.5

Table 9.3 Emulsifier function in baked goods

Emulsifier	U.S. FDA (21CFR)	EEC number
Monoglycerides and diglycerides (GRAS)	184.1505	E 471
Succinyl monoglyceride	172.830	–
Lactylated monoglyceride	172.852	E 472
Acetylated monoglyceride	172.828	E 472
Monoglyceride citrate	172.832	E 472
Monoglyceride phosphate (GRAS)	184.1521	–
Stearyl monoglyceride citrate	172.755	E 471
Diacetyl-tartrate ester of monoglyceride (GRAS)	184.1101	E 472
Polyoxyethylene monoglyceride	172.834	–
Propylene glycol monoester	172.854	E 477
Lactylated propylene glycol monoester	172.850	–
Sorbitan monostearate	172.842	E 491
Polysorbate 60	172.836	E 435
Polysorbate 65	172.836	E 436
Polysorbate 80	172.840	E 433
Calcium stearoyl lactylate	172.844	E 482
Sodium stearoyl lactylate	172.846	E 481
Stearoyl lactylic acid	172.848	–
Stearyl tartrate	–	E 483
Sodium stearoyl fumarate	172.826	–
Sodium lauryl sulfate	172.822	–
Dioctyl sodium sulfosuccinate	172.810	–
Polyglycerol esters	172.854	E 475
Sucrose esters	172.859	E 173
Sucrose glycerides	–	E 474
Lecithin (GRAS)	184.1400	E 322
Hydroxylated lecithin	172.814	F 322
Triethyl citrate (GRAS)	184.1911	–

The specification and assay procedures for all emulsifiers are published in the Food Chemical Codex (Food Chemicals Codex, 2004).

Bakery products are the largest users of food emulsifiers (Stauffer, 1996a). Yeast raised and chemically leavened products are the most important segments. Food emulsifiers are also included in cookies, crackers, pasta, and snacks. Recent figures indicate about 400,000,000–500,000,000 pounds of emulsifiers are used in the U.S. food industry with a market value of about $500 million. The baking industry accounts for about 50% of the total food emulsifiers market (Brandt, 1996). Annual growth in the production of food emulsifiers is estimated at about 2.0–3.0%.

9.5 Role of the Shortening

The shortening when mixed into a hydrated dough or batter interrupts the development of the gluten network. Literally, the structure is “shortened” and the baked product is tender. The shortening also contributes to the quality of the finished product by imparting a creamy texture and rich flavor, tenderness, and uniform aeration for moisture retention and size expansion. The oil or fat based ingredients are formulated and processed to a plasticity that allows spreadability and dispersion thoroughly and uniformly in a dough, icing or batter over a wide temperature range. The ability of the fat to disperse in streaks or films helps to lubricate the structure of the dough during mixing. The fat dispersion prevents the starch and protein in the flour from compacting into a dough mass (Stauffer, 1996a).

The characteristics of the fat that are important for shortening formulations include melting point, oxidative stability, solid fat index and plasticity. Plasticity is used to define the characteristics of the shortening that are most important to its functionality (Erickson and Erickson, 1995).

Shortenings are processed to various plasticity ranges (Weiss, 1983; O’Brien, 1995a). Narrow plastic range ingredients have a steep solids profile and melt rapidly. These ingredients are commonly used in cream icing products or as a filler fat for hard cookies where melting near body temperature is required. Wide plastic range shortenings contain 15–30% solids over a broad temperature range and resist breakdown during creaming. Their plastic nature enables them to spread readily and combine thoroughly with the other solids or liquids without breaking or having liquid oil separating from the crystalline fat. Commercial shortenings are prepared by carefully cooling, plasticizing and tempering of correctly formulated blends of melted fats and oils. The plasticizing process is often referred to as “Votation.”

The size of the fat crystals in a plasticized shortening has a major influence on the rheological properties of the shortening. A small crystal size with a large surface area is required to bind the liquid oil in the shortening. Typical crystal sizes are from 5 μm to 9 μm (Chawla and deMan, 1990). Crystal size is controlled by the source of the hard fat used (O’Brien, 1996b). The smaller crystalline form is referred to as β’ and the larger form is β. Plastic shortenings in the β’ configuration consist of small, uniform, needle-like crystals with a smooth texture. These aerate well and have excellent creaming properties.

Two major sources of β' crystalline fats are often used in formulation of votated shortenings. These are cottonseed and palm oil, often fully hydrogenated to less than 10I.V (iodine value). The use level varies from 8% to 15% of the final shortening formula.

9.6 Role of the Emulsifier

Addition of emulsifiers to the shortening promotes the emulsification of the shortening in the dough or batter. Much of the development of shortenings has concentrated on the addition of the emulsifier or emulsifier system to an all-purpose shortening base although specialty liquid, narrow plastic range, and special purpose emulsified products have been produced (O'Brien, 1995a). Today, because of the focus on trans fatty acid free ingredients, much interest has focused on emulsifier systems that permit the use of nonhydrogenated, trait modified oils as the shortening.

The general benefits of including emulsifiers in shortenings are

1. Increased shelf-life.
2. Improved tenderness and flavor release.
3. Reduced mixing time and mixing tolerance.
4. Improved machinability.
5. Better water absorption.
6. Improved volume.
7. Improved hydration rate of flour and other ingredients.
8. Better texture and symmetry.
9. Reduced egg and shortening usage.

9.6.1 Monoglycerides and Derivatives in Bakery

The monoglycerides in their many forms are the most used emulsifier in bakery products. Seldom is an ingredient label found that does not list this type of emulsifier. The preparation of monoglycerides begins with reacting glycerin with edible fats and oils or fatty acids in the presence of a catalyst (Henry, 1995). The important characteristics are melting point and monoglyceride content. Commercially available products vary from 40% to 95% monoglyceride content. Two crystalline forms are generally present: alpha and beta. The alpha form is the most functional in bakery products. The major variables involved in the production of monoglycerides are source of the fat, monoglyceride content, iodine value or degree of unsaturation, and fatty acid composition. Approximately 300 million pounds of monoglycerides are used in the United States in yeast-raised bakery products (Knightly, 1988). An equal amount was believed to be used in cakes, icings, and other applications. Cakes prepared with shortenings containing monoglycerides have improved aeration and sugar holding capacity. Breads possess an improved shelf life due to retarded staling rate. Various techniques have been used to improve monoglycerides through chemical modification or formulation with additional emulsifiers. The monoglycerides marketed for bakery applications include plastic, hydrated, powdered and distilled monoglycerides.

In addition to their antistaling benefit, monoglycerides in bakery products results in

- Reduction of interfacial tension.
- Improved dispersion of ingredients.
- Increased aeration.
- Greater foam stability.
- Modification of fat crystal (Orthoefer, 2006b).

Several derivatives of monoglycerides are prepared (Fig. 9.1). Two main functional types are generally found in bakery applications: dough strengtheners and alpha tending monoglycerides. The “dough strengtheners” includes syccinylated monoglycerides (SMG), ethoxylated monoglycerides (EMG), and diacetyl tartaric acid esters of monoglycerides (DATEM). They are also used as emulsifiers, starch and protein complexing agents, and foam stabilizers. The alpha-tending emulsifiers includes GMS (glycerol monostearate), LacGM (lactylated monoglycerides), AcMG (acetylated monoglycerides), and PGME (propylene glycol monoesters). The alpha-tending emulsifiers, normally used in cake mix production contribute to the emulsification of the shortening in the water phase of the batter as well as incorporating air into the fat phase. The alpha tending monoglycerides are believed to form a film at the oil/water interface resulting in a stable emulsion preventing the liquid oil present in the shortening from interfering with aeration during cake batter mixing.

9.6.2 Sorbitan Emulsifers

Sorbitan monostearate is a commonly used oil soluble, low HLB nonionic emulsifier. Reaction of the sorbitan esters with ethylene oxide results in the formation of the polyoxyethylene sorbitan monostearate or polysorbate emulsifiers (PS60 or polysorbate 60) (Fig. 9.2). Sorbitan esters are excellent emulsifiers for improving aeration, gloss and stability of icings. They generally function as emulsifiers, aerating agents, and lubricants in cakes, toppings, cookies and crackers. Polysorbate 60 is often used as a dough strengthener at about 0.2% of flour weight. Polysorbate 60 is also used in combination with glycerol monostearate and propylene glycol monostearate in fluid cake shortenings.

9.6.3 Anionic Emulsifers

The anionic emulsifiers include SMG, DATEM and other lactic acid derivatives (Fig. 9.3). Sodium stearoyl lactylate (SSL) and the calcium form is widely used. Both are employed as dough strengtheners.

SSL may be added as a stabilizer to hydrated monoglycerides preparations. The lactic acid emulsifiers also act as antistaling, aeration aids and starch/protein complexing agents.

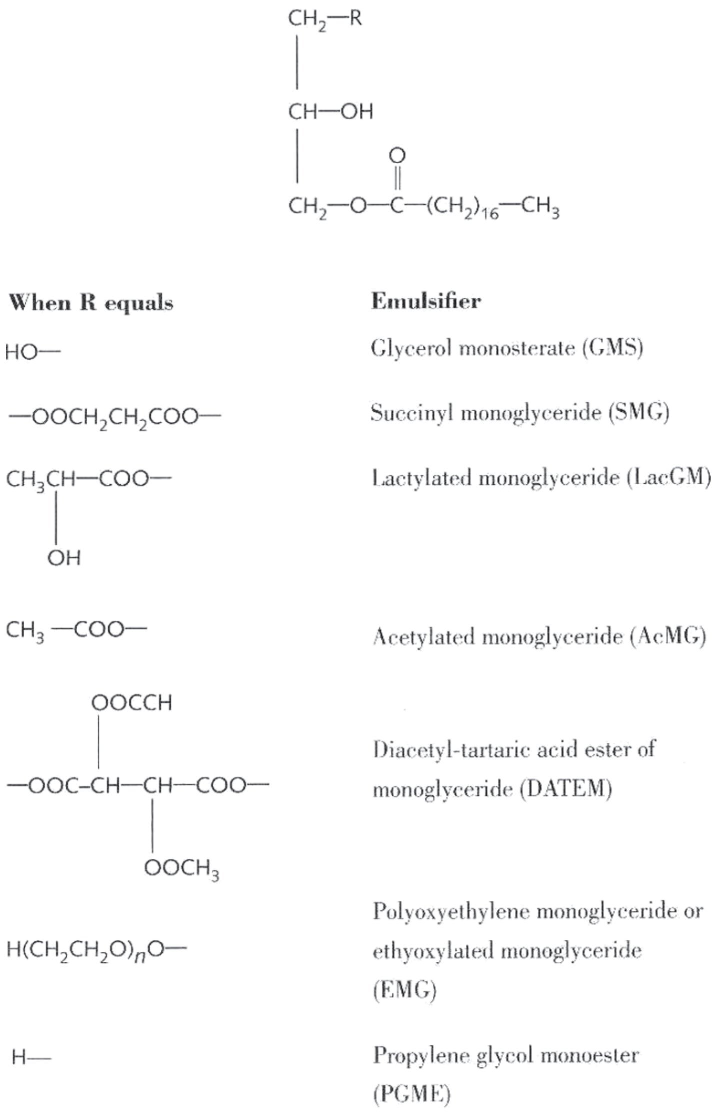
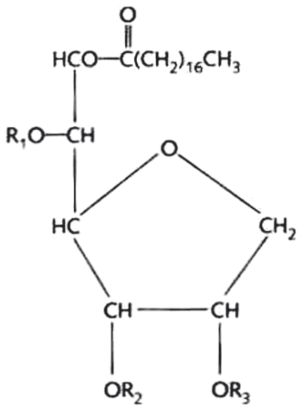


Fig. 9.1 Monoglycerides and derivatives

9.6.4 Polyhydric Emulsifiers

The main polyhydric emulsifiers are the polyglycerol esters and sucrose esters (Fig. 9.4). Both have multiple applications as emulsifiers for foods and bakery products, particularly the sucrose esters. They provide emulsifying, stabilizing and conditioning properties in baked goods. A maximum of eight hydroxyl groups in sucrose may be esterified. The degree of esterification affects the hydrophilic-lipophylic



Where

$R_1, R_2, R_3 = H$	Sorbitan monostearate
$R_1 = H\ (CH_2CH_2O)_n$— $R_2 = H$ $R_3 = H$	Polyoxyethylene (20) sorbitan monostearate (Polysorbate 60)
$R_1 = H(CH_2CH_2O)_n$— R_2 and $R_3 = H_3C\ (CH_2)_{16}CO$—	Polyoxyethylene (20) sorbitan tristearate (Polysorbate 65)

Fig. 9.2 Sorbitan esters and derivatives

balance (HLB) of the sucrose ester (Table 9.4). Sucrose esters are used as a non-caloric fat substitute when six or more of the hydroxyls are esterfied.

9.6.5 Lecithin

Commercial lecithin is a co-product of soybean oil production. Limited quantities are produced also from corn oil. Lecithin is obtained by water washing of the filtered crude soybean oil. The hydrated lecithin is easily separated from the oil and is vacuum dried. Crude lecithin is a dark colored, viscous mixture composed mainly of a mixture of phospholipids (Table 9.5). Triglycerides, tocopherols, and glycolipids are present. Various purified grades of lecithin are produced by bleaching and fractionation as well as by chemical modification (Schmidt and Orthoefer, 1985). Commercial lecithin products are specified based on the acetone insoluble

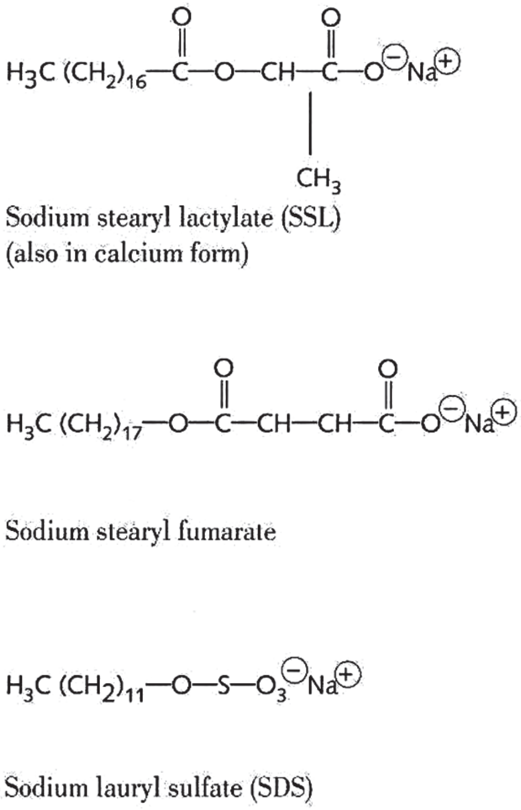
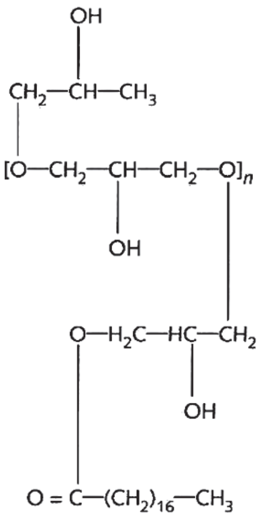


Fig. 9.3 Anionic surfactants

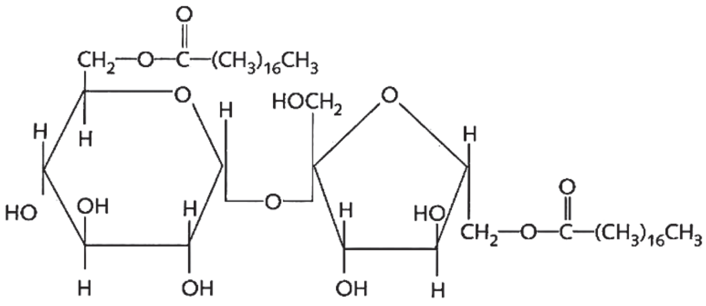
fraction (a measure of the phospholipid content), viscosity and color. Lecithin is also found in egg yolk, butter, beans, and nutmeats. Lecithin is usually an inexpensive emulsifier used for antistick properties as well as emulsification and controlled wetting of dry ingredients.

9.7 Emulsifier Interaction with Bakery Components

Emulsification and lubrication (shortening) by the emulsifier accounts only partially for the beneficial effects observed when they are added to baked products. Proteins and lipids also contribute to the functional properties of the flour. Emulsifiers interact with the various flour components especially the starch, protein and lipids, as well as the added ingredients.



Polyglycerol monostearate



Sucrose diester

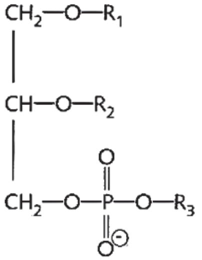
Fig. 9.4 Polyglycerol esters and sucrose esters

Table 9.4 Sucrose ester surfactants

Percent monoester	Percent diester	Percent trimester	Percent tetraester	HLB
71	24	5	0	15
61	30	8	1	13
50	36	12	2	11
46	39	13	2	9.5
42	42	14	2	8
33	49	16	2	6

From Stauffer (1996b, p 576)

Table 9.5 Lecithin



(R_1 and R_2 are fatty acids)

If R_2 = Choline ethanolamine inositol serine

Then Phosphatidylcholine

Phosphatidylethanolamine

Phosphatidyl inositol

Phosphatidylserine

9.7.1 Starch

Starch exists in a helical, coiled structure with six glucose residues per turn of the helix. This structure is a hollow cylinder with a hydrophilic outer surface and a hydrophobic inner core. The inner space is about 45 nm in diameter. Straight-chain alkyl molecules such as palmitic or stearic acid will fit in the inner space. The n-alkyl portion of emulsifiers such as present in GMS from a complex with the helical regions of the starch. It is this complex that retards starch crystallization, often called “retrogradation,” slowing the staling process.

Emulsifiers affect the cooking and swelling properties of starch (gelatinization). This may be on the rate of gelatinization, gelatinization temperature, peak viscosity or gel strength. Trials with starch pastes containing monoglycerides showed that maximum complexation occurs with monopalmitin (Lagendijk and Pennings, 1970). Longer and shorten chain saturated fatty acid monoglycerides reacted to a lesser extent. Unsaturated fatty acid monoglycerides react to a lesser extent due to the bend in the fatty acid chain at the unsaturated bond (Hahn and Hood, 1987).

Other surfactants also modify the gelatinization of starch. DATEM is generally found to be less interactive than GMS or SSL. GMS raises the swelling temperature and results in increased paste viscosity. SSL also increases paste viscosity (Schuster and Adams, 1984). Overall the interaction between emulsifier and starch takes place at the surface of the starch granule and the starch/surfactant complex stabilizes the granule, retarding water penetration and swelling as the temperature is increased (Lakshminarayan et al., 2006).

During breadmaking, only small amounts of emulsifiers are bound to starch in the sponge stage and during mixing. Binding does not occur until the temperature is increased to near the gelatinization temperature. The formation of the starch complex is principally with the amylose or linear starch fraction. Both the degree of interaction and solubilities of the complexes are dependent upon the type of emulsifier.

9.7.2 Protein

The wheat flour proteins, gliadin and glutenin, form a viscous, colloidal complex known as “gluten” when mixed into a dough. Lipids are involved in the formation of the gluten complex. The properties of gluten are dependent upon the lipids and emulsifiers present. Lipophyllic portions of surfactants interact with hydrophobic regions of proteins contributing to unfolding or denaturation of the protein. Generally, surfactants contribute to protein denaturation, enhancing interfacial adsorption and emulsion stabilization. The desired result of the protein interaction with emulsifiers is called dough strengthening.

Most commercial dough strengtheners are anionic surfactants. The association of the lipophylic portion of the emulsifier with the hydrophobic area of the protein incorporates the negative charge into the complex with subsequent aggregation in the dough. The overall effect is aggregation of the gluten protein and an increase in dough strength.

The ionic surfactants induce protein insolubilization resulting in increased viscosity and elasticity of the dough. Nonionic surfactants disrupt the hydrophobic portion of the protein leading to reduced dough viscosity and elasticity and increased protein extractability. A blend of emulsifiers generally show the best dispersability and functionality.

9.7.3 Lipids

Wheat flour contains 1.4–2.0% lipids divided into free (0.8–1.0%) and bound (0.6–1.0%) forms. They may be further divided into nonpolar (50.9%) and polar (49.1%) forms. The bound lipids exist as starch inclusion complexes. The nonstarch lipids, about 85% of the total, participate in the chemical, physical and biochemical processes important for the preparation of baked goods. The nonstarch lipids consist of glycolipids, phospholipids and stearoyl esters. Interaction between nonstarch lipids and emulsifiers is limited.

Non-polar-lipid addition to untreated flour results in deterioration of baking properties (Schuster and Adams, 1984). Addition of polar lipids to untreated flour increases loaf volume in breadmaking. The improvement is likely based on the effect of galactolipids and phospholipids. Emulsifiers may interact with the water phase of the dough, forming associated lipid-water structures with free polar flour lipids (Krog, 1981). Emulsifiers may compete with the naturally occurring lipids in wheat flour for the reactive groups of the wheat flour dough. Their effect on protein components was reduced as well.

9.8 Applications in Baked Goods

9.8.1 Yeast-Raised Products

The function of emulsifiers in yeast-raised products includes dough conditioning, strengthening and crumb-softening. The direct and indirect action of the emulsifier begins with dough preparation and ends with oven baking and storage (Fig. 9.5). The first stage begins with wetting and dispersing activity then follows with interactions with flour components during mixing and in the baking process itself.

9.8.1.1 Dough Conditioning

Dough conditioning refers to the development of less tacky, more extensible doughs. They may be processed through machinery without tearing or sticking. These doughs result in a product of finer crumb structure, improved volume and symmetry. These characteristics include

1. Increased mixing and machining tolerance of the dough.
2. Increased tolerance to variations in ingredients.
3. Diminished knockdown during handling.
4. Assist in maximum dough absorption.

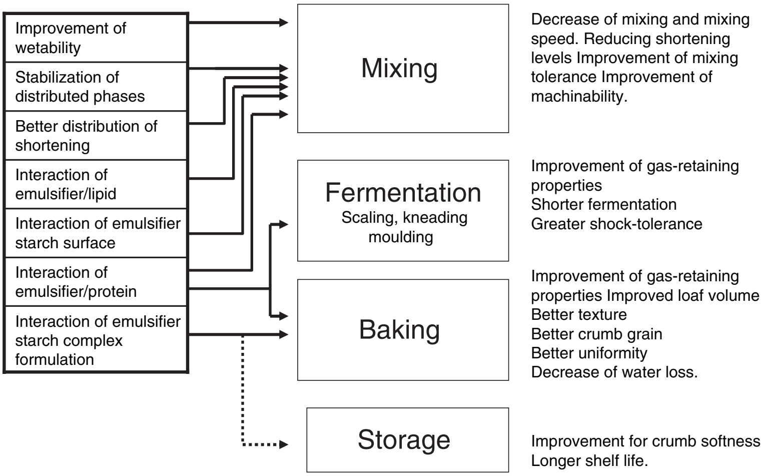


Fig. 9.5 Influence of emulsifiers on production and quality of baked products (From Schuster and Adams, 1984)

5. Reduced shortening requirements.
6. Improved loaf volume, structure, texture, and other quality attributes.
7. Extended keeping quality.
8. Facilitates variety bread production.

In the production of yeast-raised products, the mixing of the dough results in gluten–gluten bonding through disulfide linkages. Development of the linkage is often incomplete resulting in weak dough structure. The gas produced by the yeast escapes through the weak portion of the gluten films. Gas cells having weak gluten cell walls have a tendency to collapse.

Dough strengthening emulsifiers increase the degree of gluten–gluten binding sites and/or bridges that supplement disulfide linkages. This results in stronger gluten films. The benefits from the dough conditioners are

- Improved tolerance to variation in flour quality.
- Drier doughs with greater resistance to abuse.
- Improved gas retention giving lower yeast requirement, shorter proof times, and greater finished product volumes.
- Uniform internal grain, stronger side walls, and reduction of "cripples."
- Reduced shortening requirements without loss of volume, tenderness, or slicing ease.

The highly functional dough strengtheners are calcium stearoyl lactylate, ethoxylated monoglycerides (EOM), polyoxyethylene sorbitan monostearate (PS60), succinylated monoglycerides (SMG), and sodium stearoyl lactylate (SSL) (Tenney, 1978). Comparative loaf volumes found for the various conditioners are shown in Fig. 9.6 for fully proofed dough shocked to mimic abuse in production.

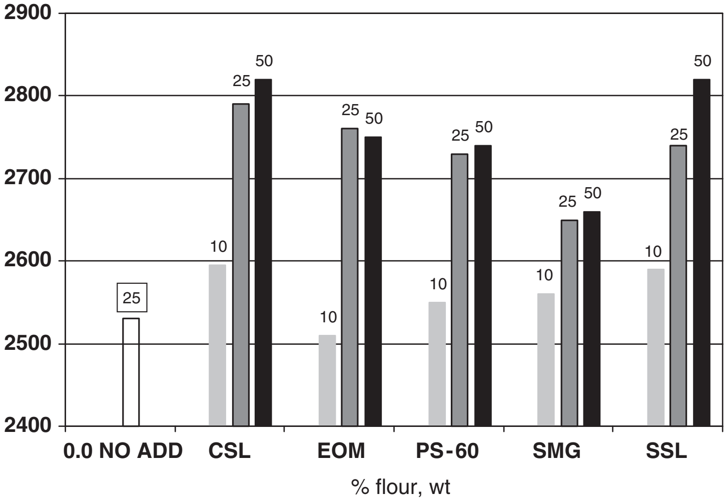


Fig. 9.6 Comparative loaf-volume response produced on abused dough by CSL, EOM, PS-60, SMG, and SSL (From Tenney, 1978)

9.8.1.2 Crumb Softening

Emulsifiers that complex with starch are referred to as “crumb softeners.” The mechanism of activity is the result of an amylose complex being formed. The staling of bread is also believed to result from amylose crystallization. During bread preparation and baking, amylose polymers associate upon cooling forming a rigid gel after 10–12h. After baking, amylopectin, the branched chain starch fraction, crystallizes more slowly resulting in firming of the bread in 3–6 days. When crumb softeners are added, less free amylose occurs and therefore less is available to form a rigid gel. The emulsifier softens the initial crumb. No change occurs with the amylopectin fraction. It gradually crystallizes to a firmer texture whether or not treated with crumb softeners.

Comparison of crumb softeners as a function of compressibility after 96h of storage is shown in Fig. 9.7. The most effective softeners are the lactylates and SMG. Plastic mono- and diglycerides and hydrated distilled monoglycerides are also effective. The polysorbate, EOM and lecithin had little starch complexing activity. The lactylates and SMG act as both conditioners and crumb softeners.

The use level of crumb softeners vary. The most commonly use crumb softeners are the water emulsions, or hydrates, of mono-diglycerides. The hydrates contain 22–25% solids and are used from 0.5% to 1% flour weight. The hydrates are

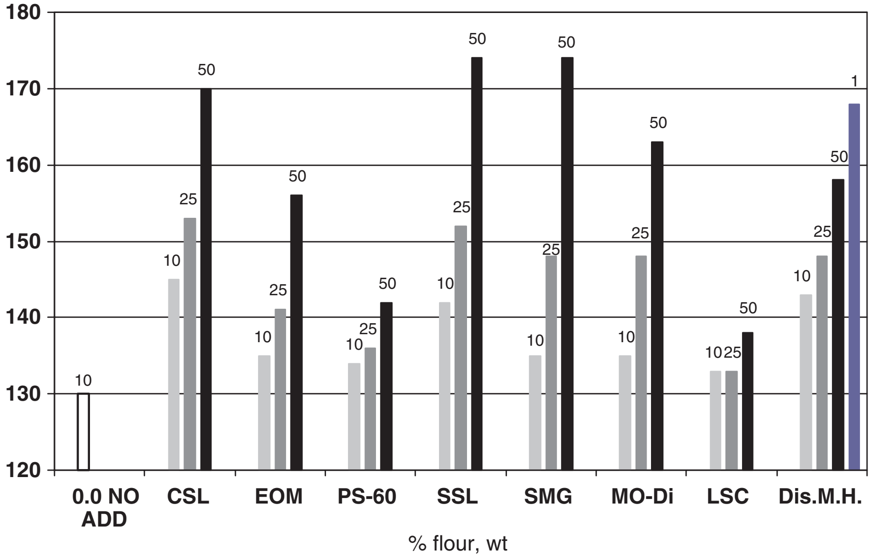


Fig. 9.7 Relative crumb-softening effect in bread by CSL, EOM, PS-60, SSL, SMG, Mo-Di (54% mono- and diglyceride), LEC (lecithin), and Dis. M.H. (22% solids distilled monoglyceride hydrate) (From Tenney, 1978)

significantly more functional than the nonhydrated forms. Water dispersible blends of distilled monoglycerides are also utilized. These blends contain unsaturated monoglycerides to promote rapid hydration in the sponge, brew or dough stage.

9.8.1.3 Emulsifier Blends

Lecithin has been used in breads and baked goods longer than any other emulsifier. Lecithin gives higher ductility through interaction with the gluten. Other activity claimed for lecithin is delayed staling and reduction of shortening. A synergistic effect also occurs between lecithin and monoglycerides. The monoglyceride–lecithin blends produce a better crumb grain, softer bread and higher loaf volumes. Ethoxylated monoglycerides combined with monoglycerides is also an effective dough conditioner. The negative effects of liquid oils in place of “solid” shortenings in bread production are overcome with this combination.

DATEM also acts as a dough conditioner, spares shortening and is an antistaling agent in combination with glycerol monostearate. Others include SMG, sucrose esters, polysorbate 60, SSL, and CSL. The SSL and CSL can form complexes with gluten acting as a dough strengthener.

9.8.2 Chemically Leavened Products

9.8.2.1 Cakes

The role of the emulsifier in layer cakes or snack cakes is diverse and includes aeration, emulsification and crumb softening. The aerated structure of batters depend on whipped-in-air and gas (CO_2) from the leavening agent. The emulsifier lowers the surface tension of the aqueous phase improving the amount of air that can be whipped into the batter. Large amounts of finely divided air cells are important for development of uniform grain (Handlemann et al., 1961). The dissolved CO_2 evolves at air cell sites and does not spontaneously form bubbles. If the original batter contains many small air cells, the final cake will have a larger volume and fine (close) grain. The creaming of the sugar and shortening has a major influence on air incorporation. The incorporation of monoglycerides in the plastic shortening (3–5% alpha-monoglycerides) ensures numerous small air cells being created during beating or creaming.

Cake batter is an aerated emulsion. The integrity of the air cells determines cake volume and uniformity. Shortening is antifoam that disrupts foam cells. Emulsifiers, however, coat the exterior of the fat particles protecting the integrity of the air cell (Wooten et al., 1967). Use of appropriate emulsifiers has permitted the use of liquid oils where only solid shortening could previously be used.

Light, tender, moist cakes are preferred by the consumer. Emulsifiers provide the desired aeration, emulsification and crumb softening. Crumb softening in cakes is a function of moisture retention, shortening activity, and starch complexing. It is the same as for breads. The emulsifier complex with the starch softens the product.

Several types of emulsifiers are used in cakes. Propylene glycol monoester (PGME) is used at 10–15% of the shortening. Monoglycerides and mixtures of lactated monoglycerides with PGME are also used in cake mixes.

In baker's cakes, emulsifier selection depends on formula, production equipment, and labeling requirements. Using soybean oil as the shortening, a hydrated blend of emulsifiers such as PS 60, SSL, sorbitan monostearate, and distilled monoglycerides works well. Fluid shortenings are produced containing lactated monoglycerides. The traditional baker's cake system is a plastic shortening with 5–10% monoglycerides (4% alpha-monoglyceride content). Packaged cake mixes often use emulsified PGME at 10–15% of the oil. The cakes are unusually tender and are not suited to commercial cake production.

Emulsified cake shortenings are also used for cake donuts. The amount of air entrapped during creaming determines the grain in the final donut.

9.8.2.2 Cookies and Crackers

Emulsifier use in cookies and crackers is limited. They do play a role in controlling spread, improve cutting and appearance, and improve texture.

Certain emulsifiers control spread of the cookie dough during baking (Table 9.6). This likely occurs because of modification of the viscosity of the dough. Cookie dough with SSL shows increased spread compared to a nonemulsified control (Rusch, 1981). The SSL may interact with the starch granule delaying hydration of the granule and subsequent gelatinization (Tsen et al., 1973).

Lecithin may be used to produce a drier dough that machines better and releases easier from a rotary die surface. Use is from 0.25% to 0.7% of the flour. Part of the effect may simply be reduction of available water because of lecithin hydration.

Table 9.6 Spread ratios of cookie doughs with different emulsifiers

0.5% additive	Spread ratio
Monoglyceride	8.3
Ethoxylated monoglyceride	8.8
Sodium stearoyl fumarate	10.4
Sodium stearoyl lactylate	10.0
Sucrose monopalmitate	9.8
Sucrose mono- and distearate	9.6
Sucrose distearate	9.7
Sorbitan monostearate	9.2
Polysorbate 60	9.3
Succinylated monoglycerides	9.2

From Tsen et al. (1973)

Lecithin that is highly fluidized with other oils or fatty acids is widely used as a release agent in cookie baking for release from rotary dies. Heat-resistant lecithins such as those modified with acetic anhydride are especially adaptable to this application. Lecithin is used in cookie and cracker formulations at 0.25–1.0% of flour weight. It may be added with the shortening at the creaming stage or simply combined with the shortening when votated.

Antistaling is of less significance in cookies and crackers since they are of lower moisture content. The greasiness of high shortening levels is reduced by the addition of small amounts of lecithin. Lecithin in general produces a "drier" dough with equivalent moisture and shortening levels. The drier dough is more machinable. Other benefits attributed to lecithin are reduced mixing times and dough development with more tender cookies.

SSL is also promoted for cookies and cracker improvement. When incorporated into the dough at 0.25%, flour basis, the SSL produces a finer grained, more uniform pattern of surface cracks. The resistance to shear (firmness) decreases, improving eating quality and permits reduction in shortening (Tenney, 1978). Levels are 0.25% SSL in cookies and 0.1% in crackers based on flour weight.

9.8.3 Extruded Snacks/Cereals

Extrusion cooked snacks, pasta, and cereals often include emulsifiers in their formulas. Gelatinization of the starch occurs during the cooking/extrusion step. Monoglycerides and SSL have been found to reduce the energy required for the extrusion and to produce a desirable texture in the final product. Monoglycerides are added to improve the appearance and smoothness of the extrudate and produce a finer pore structure. Use levels are 0.25–0.5% of the starch weight and is added at the dough make up stage.

9.8.4 Cream Icings

Cream icings are prepared by creaming sugar with fat, then adding flavor, egg white and perhaps a small amount of water. The emulsified shortenings used contain 2–3% alpha-monoglyceride. PS60 at 0.5% is included in some icings to assist in aeration. PGME when incorporated into the shortening produces icings with excellent gloss and gloss retention.

9.8.5 Fat-Free Bakery Products

Fat free and low fat foods are marketed in almost every segment of the food industry. In most instances, there is no single solution for removal of fats from the formulation.

Skillful formulation using fat replacers, emulsifiers, bulking agents, flavors, and other ingredients have been applied to fat replacement.

Low fat and fat free cakes have been produced using additional emulsifiers in conjunction with starch based replace and gums or hydrocolloids for moisture retention and functionality. PGME and DATEM have proved to be particularly useful.

Emulsifiers are not generally regarded as fat substitutes or replacers. Emulsifers affect the texture and mouthfeel by their surface activity. The caloric value of emulsifers vary depending on their composition and digestibility. They tend to have fat-like properties through their hydration, water binding, and dispersing effects in processed foods. The general function of emulsifiers in low-fat and no-fat applications are

- Prevent separation of components.
- Reduce size of fat globules and improve dispersion of remaining fat.
- Provide fat sparing action.
- Provide texture perception of higher fat contents.
- Texturize and provide lubricity.
- Complex with starches and proteins.

Mono and diglycerides are the most used emulsifiers. Distilled monoglycerides have lower calories compared to the lower mono content preparations. Other emulsifiers in reduced fat products include the polysorbates, DATEM, polyglycerol esters, and sorbitan esters. Emulsifiers used in products having sucrose esters and mixed esters of short and long chain tri-esters are replacers is very likely similar to that utilizing traditional caloric versions.

9.8.6 Release Agents

A separate application of emulsifiers in bakery products, although not incorporated in the dough, is release agents or pan sprays. Lecithin is the primary emulsifier used. Often the pan sprays are formulated with an oil in combination with mold inhibitors and lecithin. 1–6% lecithin is added. Modified lecithins that possess improved heat stability may be used. The pan spray may simply be brushed on or sprayed to achieve a thin film promoting easy release of baked products from pans or belts.

9.8.7 Trans-Free Shortening

Consumption of trans fatty acids has negative health consequences. As much as 40% of the trans fatty acids in the diet are from shortenings used in bakery product (Orthoefer, 2006b). These originate from the partial hydrogenation process used to produce the shortening. Partial hydrogenation results in oxidatively stable products with the desired properties of shortenings. Alternatives to partially hydrogenated shortening include simple blending of commodity oils with fully hydrogenated hardfats, interesterified products, use of naturally saturated oils such as palm oil and fractions, and trait modified oils (Cowan and Husum, 2004). For those applications using trans-free shortening, the traditional emulsifiers such as GMS function similarly. Shelf stability of the finished products, particularly with the trait modified oils, seems to not be affected (Orthoefer, 2006a).

9.9 Summary

The market for emulsifiers for bakery products continues to increase. As with many industries, bakeries have undergone consolidation. Fewer producers have placed greater requirements on the final products such as longer distribution, longer time from production to consumption, greater stability and shelf-life. The function of the emulsifier is of ever greater importance. Growth in food service increases the need for bakery products having desirable sensory and performance characteristics to meet the demands of tomorrow's market place.

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