Chapter 22

Application of Diacylglycerol Oil in Baked Goods, Nutritional Beverages/Bars, Sauces, and Gravies

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Use of Diacylglycerol Oil in Food Products

Because consumption of diacylglycerol (DAG) oil can have a positive effect on weight management (see Chapters 9–11), visceral fat (see Chapter 10), postprandial (see Chapters 6–8) and fasting triglycerides (see Chapters 11 and 12), and appetite suppression (see Chapter 5), there has been great interest in incorporating this oil into a variety of food products. Not only would the use of DAG oil provide clinical benefits through consumption of 1,3-DAG, but in many cases, it would also reduce the intake of saturated and *trans* fats through partial replacement of vegetable shortening or dairy fat. By replacing vegetable shortening or dairy fat with DAG oil, the levels of polyunsaturated and monounsaturated fats in the food product increase, which subsequently increases the overall healthful value and nutritional benefit of the product. The level of DAG oil substitution is influenced by the application or product category in which diacylglycerol oil is used to replace triacylglycerol (TAG). In this chapter, the utilization of DAG oil in various baked goods, nutritional supplements, meal replacement beverages, sauces, gravies, and frozen entrées will be discussed.

Use of DAG Oil in Cookies

To understand the effects of DAG oil in cookies and how best to incorporate it into the dough, one must first understand the factors that have the greatest effect on cookie quality. The type of fat, sugar, and flour selected will each have a significant effect on the texture and appearance of the finished product, regardless of cookie type.

Fat imparts a variety of beneficial properties to the cookie dough and to the finished cookie. Fat lubricates the dough and aids in aeration of the dough before baking (1). It also aids in flavor release and helps to provide the desired texture and mouthfeel characteristics in the finished product (2). In addition, the type of fat selected can have a great effect on dough viscosity, directly influencing the type of manufacturing equipment that can be used to process the dough (3). Typically, some type of plastic fat (such as shortening, margarine, butter, or lard) is used for most cookies (4). The solids contributed by the plastic fat provide a framework for air entrapment during the creaming stage, which increases the volume in the finished cookie and provides the

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desired textural attributes (4). Because liquid fats and oils do not contain the same level of solids as plastic fats, they are not able to incorporate volume to the same extent as plastic fats; consequently, their application in cookies has been somewhat limited up to this point (1).

Cookies using plastic fat will tend to be more crisp and have better snap, whereas cookies using liquid oils or fats will tend to be softer, more tender, and less crisp than their plastic fat counterparts. Depending on how much liquid oil is incorporated into the formula, manufacturing problems may arise. If a high portion of liquid oil is added, the dough will become very flowable and sticky, making it difficult to process using conventional wire-cutting or rotary die equipment (4). Consequently, using a deposit or extrusion set-up may be necessary when producing products containing low levels of solid fat (3).

Sugar has a large effect on the functional properties and appearance of cookies. The type of sugar used can affect the spread, texture, and appearance of the finished cookie (4). The most common type of sugar used in cookies is granulated sugar; however, corn syrups are used in applications such as soft-batch cookies in which extra water binding and softness are required in the finished product (4). In a typical cookie, granulated sugar is partially solubilized by the formula water present due to moisture constraints (2). During baking, the sugar melts, resulting in a more fluid dough, which allows the cookie to spread (2). Coarsely ground sugar absorbs less water, yielding less spread, a higher degree of surface cracking, and a crisp, hard texture in the finished cookie, whereas finely ground sugar absorbs more water, yielding greater spread, less surface cracking, and a softer texture in the finished cookie (2,4).

The type of protein/flour used can also have a significant effect on cookie performance. Most flours used in cookie manufacture are derived from soft wheat (2), which has a lower protein/gluten content than hard wheat. Higher protein contents in hard-wheat varieties generally yield tougher textures, reduced spread, and less surface cracking in cookies than their soft-wheat counterparts (4). Because both protein and sugar fractions compete for the available water in the system, the gluten fraction in cookies is typically not hydrated to a great extent (2). Lack of gluten development is an advantage in cookie dough because development of the gluten would make the dough more difficult to process through wire-cut, rotary, deposit, or extrusion set-ups and would give the finished cookie a tough, undesirable texture (4). The only exception with respect to development of gluten proteins occurs when sugar syrups are used in the formulation. Because the sugar syrups provide a higher level of available moisture in the formula, the gluten is able to more fully hydrate and develop (gluten cannot develop if it is not hydrated) (4). However, due to the humectant properties imparted by the sugar syrups, the texture of the cookies is not negatively affected, and softness of the final product is maintained.

Incorporation of DAG oil into cookies is fairly straightforward; it can be added as either a partial or complete replacement of the shortening typically used in cookies. It is added at the same stage as the shortening to ensure proper mixing with the shortening and sugar. To determine the optimum level of DAG oil in the cookie, a model system should be used. Once the desired level has been determined, the effect on the flavor system should be investigated. By using a liquid oil to replace part or all of the solid fat originally in the system, perception and release of flavor compounds may be altered. Consequently, minor changes in the flavor system may be required to maintain similar flavor and aroma characteristics to the original cookie. Depending on how much liquid oil is incorporated into the system, it may be necessary to alter packaging, antioxidants, bulking agents, preservatives, or crumb softeners to obtain similar shelf-life characteristics (4). Because functional attributes and desired eating quality vary depending on the type of cookie baked, similar practices should be used to determine the optimum inclusion level, flavor profile, and storage considerations for other cookie types utilizing DAG oil.

Work was done using a model sugar cookie formula to examine how DAG oil affected the functional properties, flavor profile, and shelf life of the cookie. The formula contained 40% fat, 63% sugar, and 9% protein (based on flour weight). The dough was prepared using a three-stage process. In the first stage, shortening (or oil, if applicable) was creamed with sugar to facilitate aeration. Eggs were added in the second stage to provide emulsification of the shortening and/or oil with the dry ingredients; flavor (vanilla and lemon extracts) was also added at this stage to achieve uniform dispersion before the addition of the flour. Flour and water were added in the final stage to minimize gluten development. After the dough was made, it was chilled for ~30 min, sheeted, cut, and baked. After the cookies were completely cooled, they were packaged in foil pouches and stored at room temperature to evaluate shelf life. Dough rheology and ease of machining were evaluated during make-up and manufacture, whereas spread, texture (gforce, in g, by TA-XT plus texture analyzer), water activity (by Aqualab Series 3 TE water activity meter), and moisture content (by Mettler LP 16 drying oven equipped with Mettler PM 100 balance) were evaluated at various time points over the shelf life of the cookies.

Comparison of Functional Properties in Cookies Utilizing DAG Oil at Various Inclusion Levels Relative to Shortening. To determine the effect of DAG oil in cookies, various inclusion levels relative to shortening were examined. Cookies were made in which DAG oil replaced shortening at 25, 50, 75, and 100% of the amount of shortening originally contained in the formula. Little difference was seen in make-up, dough viscosity, chill time, or sheeting properties of the dough when 25% DAG oil:75% shortening or 50% DAG oil:50% shortening blends were used. Moderate differences were seen when the 75% DAG oil:25% shortening blend was used. Although the dough was not as fluid or sensitive to temperature as the complete shortening replacement (see discussion below), it did not have sufficient structure to be easily sheeted and repeatedly worked. Consequently, a depositor or extrusion system would be recommended over a wirecut system for commercial production of cookies with this shortening:oil composition (3).

Major differences were seen when DAG oil was used as a complete replacement for shortening. Because sufficient solids were not present in the oil to provide structure, the dough was significantly more fluid than when shortening was incorporated into the dough at higher levels. Consequently, the time required to chill the dough to enable it to be machined increased from 30 to 45 min. Scrap dough was also more difficult to rework using the manufacturing procedure described; the dough was more sensitive to increases in temperature and became more sticky and difficult to handle as its temperature increased. Therefore, to produce cookies utilizing DAG oil commercially as a complete replacement for shortening, it would be necessary to use a depositor or extrusion setup to work and machine the dough efficiently.

In addition to the effects seen in dough rheology and machinability, effects in spread, texture, water activity, and moisture of the finished cookie were also compared. The control, made with 100% shortening as the fat source, had a spread (5) of 57.8 (Fig. 22.1). Cookies made with 75% shortening:25% DAG oil, 50% shortening:50% DAG oil, and 25% shortening:75% DAG oil had comparable spread results (5) of 64.2, 62.3, and 60.2, respectively (Fig. 22.1). Although the spread of these cookies was a bit higher than that of the control, they were similar in appearance to the control. In contrast, cookies made with 100% DAG oil as the fat source had considerably less spread than the control (Fig. 22.1), averaging 50.0. Moreover, the cookies made with 100% DAG oil had an appearance and texture more similar to a soft-batch cookie as opposed to a snap cookie. The texture of cookies made with 100% shortening, 75% shortening:25% DAG oil, and 50% shortening:50% DAG oil was similar (all were snap type). The texture of the 25% shortening:75% DAG oil cookie was intermediate between a soft-batch and snap cookie, but favored the soft-batch type.

Through examination of the physical and chemical changes occurring during make-up and baking of traditional cookie dough formulas, one can devise probable explanations to describe what happens when DAG oil is added to the dough at various levels. At partial replacements of up to 50% shortening, DAG oil provides lubricity and increases flowability of the dough, yielding increased spread. When DAG oil is used to replace 75% of the shortening, additional lubricity is imparted to the dough;

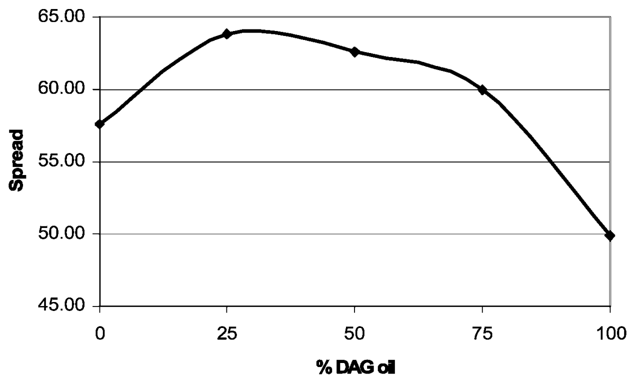

Fig. 22.1. Effect of diacylglycerol oil utilization on sugar cookie spread. DAG oil was used to replace 0, 25, 50, 75, and 100% of the all-purpose shortening typically contained in the formula.

however, the increased polarity of DAG relative to TAG allows more water to be retained during baking, which allows more gluten to be developed before the cookie is completely baked. Gluten development decreases cookie spread, changing the texture from a snap type to more of a soft-batch type. Differences in spread compared with formulations containing 25 and 50% DAG oil are minimized because the added lubricity has a positive effect on spread and increased gluten development has a negative effect on spread. When DAG oil is used to completely replace shortening in cookies, the marked increase in fluidity of the dough combined with the increased polarity of DAG relative to TAG allows even more water to be retained and a higher level of gluten to be developed. As a result, spread is further decreased and texture changes from an intermediate between a snap cookie and soft-batch cookie to one that solely exhibits characteristics of a soft-batch cookie.

Texture readings (by TA-XT plus, Texture Technologies, Scarsdale, NY), water activity, and moisture results support the hypothesis described above. No major differences were seen in texture (as measured by TA-XT plus or as described by informal sensory analysis), moisture, or water activity of cookies made with 100% shortening, 75% shortening:25% DAG oil, or 50% shortening:50% DAG oil after 4 wk (Fig. 22.2). The initial texture of cookies made with 25% shortening:75% DAG oil was similar to that of cookies made with 0–50% DAG oil; however, after 4 wk, these cookies became firmer and had a slight hard/stale texture relative to cookies made with 0–50% DAG oil (Fig. 22.2). Water activity was higher (~0.50 vs. 0.45) although moisture was about the same (4.7 vs. 4.5%) in cookies containing 75% DAG oil compared with cookies containing 0–50% DAG oil. Cookies made with 100% DAG oil had texture scores similar to those of other cookies for the first week after manufacture; however, the texture became progressively firmer and increasingly stale in subsequent weeks (Fig. 22.2). After 2 wk, the cookies made with 100% DAG oil were judged to be too stale for consumer acceptance. Both water activity (0.54 vs. 0.45) and moisture scores (6.3 vs. 4.5%) were notably higher in 100% DAG oil cookies compared with cookies containing shortening or blends of shortening and DAG oil. To compensate for these increases in water activity and moisture, it may be necessary to add preservatives to maintain a shelf life similar to that of shortening-based cookies.

Investigation of Crumb Softeners

Effect of High Fructose Corn Syrup (HFCS). Additional methods were investigated to improve the texture and keeping qualities of cookies containing 100% DAG oil. One of the ingredients investigated was high-fructose corn syrup (HFCS). HFCS is used as a humectant in soft-batch cookies (4); because the cookies with 100% DAG oil had a soft-batch quality, it was reasoned that HFCS might prolong this character and improve shelf life through improved management of moisture. Formulations using HFCS to replace 15% of the granulated sugar in the formula were unsuccessful because the dough was extremely fluid and too sticky to work with using available equipment. Therefore, HFCS was abandoned in favor of more conventional crumb softeners having less effect on dough rheology.

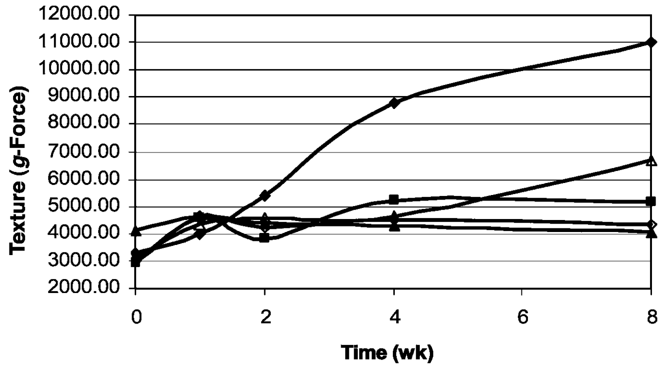

Fig. 22.2. Effect of diacylglycerol oil utilization on texture of sugar cookies. DAG oil was used to replace 0 (△), 25 (▲), 50 (◇), 75 (■), and 100% (◆) of the all-purpose shortening typically contained in the formula.

Effect of Traditional Crumb Softening Agents. Additional crumb softeners investigated included distilled monoglycerides (DMG), deoiled lecithin, polyglycerol esters (PGE), and sodium stearoyl lactylate (SSL). The formula and manufacturing procedure were the same as previously described; equivalent levels of softener (1%, flour weight basis) were used in each treatment. Although it would be necessary to adjust the level of some softeners in practice (due to limitations based on flavor, permitted use in the category, for example), each was compared at the same level to compare performance properties on an equivalent basis. In addition to comparing performance properties of shortening and DAG oil, performance properties of TAG oil (with oils selected to match the fatty acid composition of the DAG oil) were also examined. All oils tested were tested as pure systems; in other words, no blending of shortening, DAG oil, or TAG oil was done in this study.

Formulations prepared with distilled monoglycerides [iodine value (IV) = 20] showed improvement in hardness values in all three treatments in the initial and 1-wk results (Figs. 22.3 and 22.4). However, results showed little improvement compared with the control after 1 wk (Figs. 22.3 and 22.4). These results support existing work in the literature which shows that there is little, if any, gelatinization of starches in cookies during baking (4). As a result, crumb softeners that function by interfering with starch retrogradation will most likely have a minimal effect on improving the shelf life of cookies.

Formulations prepared with deoiled lecithin showed large increases in spread in all treatments (Fig. 22.5). Spread (5) increased from 57.6 to 66.8 in cookies made with shortening, from 50.0 to 57.8 in cookies made with DAG oil, and from 60.7 to 69.0 in cookies made with TAG oil (Fig 22.5). Increases in spread resulted from modification of dough rheology before baking, which was noted in each of the three doughs immediately after make-up. Because the doughs made with liquid oils (either DAG or TAG oils) were inherently more fluid, the addition of deoiled lecithin caused them to be

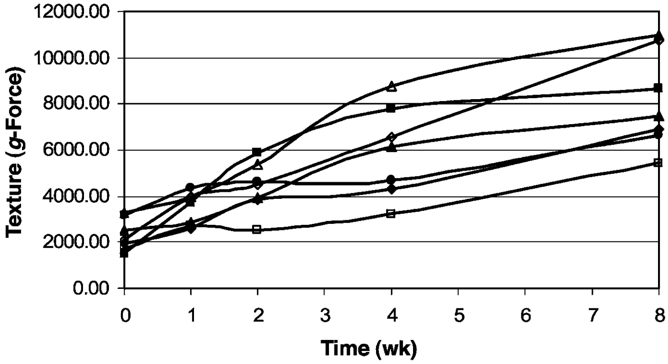

Fig. 22.3. Texture of 100% DAG oil cookies made with various crumb softeners. Crumb softeners used were as follows: DMG (■), 3-PGE (◇), 10-PGE (◆), deoiled lecithin (▲), and SSL (□). In addition, results for the diacylglycerol oil control [100% DAG as fat source, no crumb softener] () and overall control for the process [100% shortening as fat source, no crumb softener] (●) are shown.

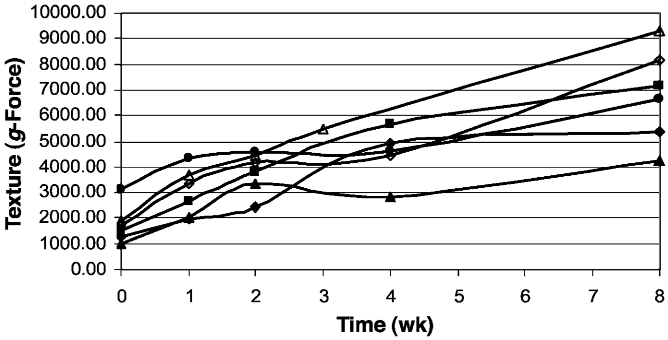

Fig. 22.4. Texture of 100% TAG oil cookies made with various crumb softeners. Crumb softeners used were as follows: DMG (■), 3-PGE (◇), 10-PGE (◆), and deoiled lecithin (▲). In addition, results for the triacylglycerol oil control [100% TAG as fat source, no crumb softener] (△) and overall control for the process [100% shortening as fat source, no crumb softener] (●) are shown.

stickier and more difficult to handle than when they were processed without additives. Because the dough made with shortening had solid fat present to help build structure and provide the desired handling characteristics, the addition of deoiled lecithin increased fluidity of this dough without negatively affecting its handling or machining properties.

Improvements in texture were noted in all three treatments when deoiled lecithin was used; however, more pronounced and lasting effects were seen in shortening and TAG oil treatments than in the DAG oil treatment (Figs. 22.3 and 22.4). When deoiled lecithin was used as a crumb softener in cookies made with shortening or

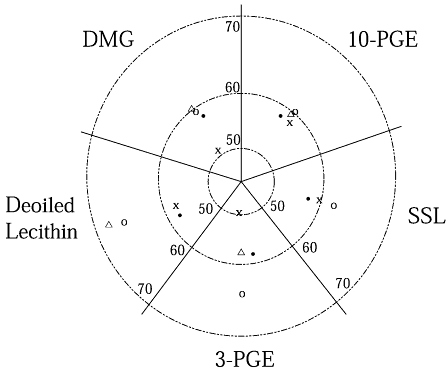

Fig. 22.5. Effect of fat/oil source and crumb softener type on sugar cookie spread. Cookies were made with 100% shortening (○), 100% DAG oil (x), or 100% TAG oil (△) as the fat source. In addition, the control for the process [100% shortening as fat source, no crumb softener] (•) is shown.

TAG oil, texture readings recorded at 4 wk in the deoiled lecithin treatments were similar to those recorded initially in the control (Fig. 22.4). In contrast, the deoiled lecithin treatment made with DAG oil had texture readings at 2 wk similar to those recorded initially in the control (Fig. 22.3); at 4 wk, a crumbly, stale texture began to emerge. Therefore, it was reasoned that deoiled lecithin alone would not be suitable to extend the shelf life of cookies using DAG oil as a complete replacement for shortening. Deoiled lecithin may be suitable for cookies using TAG oil as a complete replacement for shortening; however, the level would most likely have be reduced because there were very slight, but notable, off-flavors and aromas present at the 1% inclusion level.

In addition to distilled monoglycerides and deoiled lecithin, two different types of polyglycerol esters [triglycerol monostearin (3-PGE) and decaglycerol monostearin (10-PGE)] were investigated to determine their utility as crumb softeners in cookies. The different PGE were selected to determine whether the degree of polymerization of the polyglycerol chains had an effect on crumb softening power. Minor improvements were seen when 3-PGE was used (Figs. 22.3 and 22.4); however, because the improvements were not significant and would not have the necessary effect on shelf life, no further exploration was done with this additive. Notable improvements were seen when 10-PGE was used to extend the shelf life of cookies made with DAG oil. Spread increased (50.0 to 57.1) (5) to values seen in shortening-based cookies (57.6) without affecting dough rheology (Fig. 22.5). In addition, DAG oil–based cookies made with 10-PGE had a softer texture for a longer period of time than DAG oil–based cookies made with the previously discussed crumb softeners (Fig. 22.3). Despite improvements in texture, spread, and dough rheology, improvements were not sufficient to yield more than a 4-wk shelf life; thus, the use of 10-PGE as the sole crumb softening agent in DAG oil-based cookies was ruled out.

Of the crumb softeners tested, SSL appeared to be the most promising in DAG oil. Use of SSL increased spread (5) in DAG oil–based cookies from 50.0 to 58.5, making the spread similar to that of the shortening-based control (Fig. 22.5). Use of SSL did not change the rheological properties of the dough before baking, enabling the dough to be more easily handled and machined compared with other crumb softeners. In addition to the positive change in spread, positive changes were also noted in texture. In fact, when SSL was used as a crumb softener in cookies containing DAG oil, texture readings recorded at 4 wk in the SSL treatments were similar to those recorded initially in the control (Fig. 22.3).

Cookies made with shortening displayed similar trends with respect to spread (increasing from 57.6 to 61.6) and texture when SSL was used (Fig. 22.5). As with DAG oil, no changes were seen in dough functionality or handling when SSL was used in cookies made with shortening. Although use of SSL provides some distinct advantages over other crumb softeners tested, it is important to note that this study was designed to compare all crumb softeners equally; thus, SSL was used at a level exceeding the level permitted in cookies by the Code of Federal Regulations (CFR). Therefore, to fully elucidate the benefit of SSL in cookies for commercial manufacture, additional testing at levels within the permitted use requirements would be required.

Use of DAG Oil in Cakes

Cakes and cookies are similar in the fact that they both have high levels of sugar incorporated into their respective formulations; however, because the water content in cake is so much higher than that of cookies, the sugar in cake completely dissolves in the batter, leaving a tender product devoid of sugar crystals (2). Because the amount of available water in the batter is high, starches can gelatinize during baking, locking incorporated air into place and setting the structure in the finished cake (2). High amounts of available water also allow more thorough development of the gluten, which, in turn, affects the structure of the finished cake (6). The type of fat, emulsifier, leavening agents, and flour selected each has a significant effect on volume, texture, and appearance of the finished product, regardless of cake type.

Effect of Formula Ingredients on Cake Quality

Arguably, the ingredients that have the most significant effect on cake volume and texture are fat and emulsifiers. Fats aid in air entrapment, providing volume in the finished cake (2). They also lubricate protein and starch fractions, disrupting structure formation, yielding increased tenderness and fine crumb grain (6). Use of emulsifiers improves the functionality of fat by reducing the surface tension between fat and the aqueous phase, allowing the fat to be more completely dispersed, which enhances the formation of smaller air cells and improves air incorporation and crumb grain (6,7). Because the fat is dispersed into small particles over a large surface area, lubrication of dough and water-holding capacity of the batter are improved, giving a more tender crumb and longer shelf life (7).

Fats selected can be either shortening, emulsified shortening, or fluid shortening (1,6). The type of fat selected and level of fat used will affect cake tenderness and volume (1). Comparisons of cakes made with emulsified and fluid shortenings showed that fluid shortenings could provide greater volume, finer grain, greater water-holding capacity, improved batter flow, and greater mixing tolerance than cakes made with emulsified shortening (1). Not only could improvements in performance be gained through the use of fluid shortenings, but healthier consumption alternatives could also be realized by replacing more of the solid fat with liquid oil.

In addition to the type of fat used, the selection of appropriate leavening agents is important for proper air incorporation and growth of air cells during baking. Typically, a baking powder that contains a mixture of slow- and fast-acting leavening acids is used in cakes (7). The fast-acting type aids in nucleation of air cells in the batter, increasing the amount of air incorporated within the solid fat (2). The slow-acting type works in the oven through expansion of the batter, aiding in growth of air cells formed during the creaming stage (2). Proper selection of fast- and slow-acting leavening acids will be influenced by the type of cake to be produced, as well as the process and equipment being utilized.

Due to the large amount of moisture present in cake batters, gluten development takes place to a higher extent in cakes than in cookies (6). To allow sufficient gluten development to occur without creating excessive toughness, the protein content of cake flour should be ~6–8% compared with 8–10% for pastry (cookie) flour (8). In addition to a lower protein content, it is also important to use a bleached cake flour rather than an untreated cake flour (2). It is thought that the bleaching aids in the swelling of the starch, which increases the viscosity of the cake batter (2). By increasing viscosity of the cake batter and providing a more ordered structure for air entrapment, coalescence and subsequent collapse of air cells is reduced, yielding increased volume in the finished cake (2).

Although used at very low levels in cakes, pregelatinized starches and hydrocolloids can have a significant effect on dough rheology and moisture retention. Typically, pregelatinized starches are used to provide increased viscosity in the batter before baking (7), which allows more air to be retained within the batter, giving the finished cake increased uniformity and finer grain (6). Hydrocolloids, such as carboxymethylcellulose (CMC), guar gum, or xanthan gum, not only provide increased batter viscosity, but also increase moisture retention and softness and improve the shelf life of the finished cakes (6,7).

Effect of the Mixing Processes. The two mixing processes most widely used in cake manufacture are multistage mixing and single-stage mixing. Multistage mixing is used in the production of scratch cakes (typical in commercial production), whereas single-stage mixing is used to produce cakes from box mixes (typical in home use) (2). In multistage mixing, shortening (either emulsified or fluid) and sugar are creamed together to disperse fat and facilitate development of small air cells (2). The addition of liquids (such as water and eggs) and flour takes place in subsequent mixing stages.

During baking, the shortening melts, releasing air cells into the aqueous phase, allowing them to combine with the leavening acids to expand and provide volume in the finished cake (2). Because a separate creaming stage is used to nucleate the batter, air incorporation is quite efficient, yielding cakes with high volume, tender crumb, and fine grain; consequently, cakes made by multistage mixing techniques tend to be more resilient and better able to withstand the abusive conditions encountered in shipping and distribution (2).

In single-stage mixing, shortening and emulsifiers are melted together and plated onto the dry ingredients, allowing the fat system to be thoroughly dispersed within the mix (2). Liquids, such as water, milk, eggs, and oil, are then added to the dry mix. Because all dry ingredients and liquids are present at the same time, a creaming stage is not possible. Thus, nucleation of air cells takes place directly in the aqueous phase as opposed to being encapsulated in the fat phase (2). Because air cells are not encapsulated in fat, they are more mobile in the aqueous phase, which leads to coalescence and formation of larger air cells as well as increased air loss (2). As a result, cakes made from single-stage mixing are generally lower in volume, have coarser, more open grain, and are less resilient than cakes made from multistage mixing.

Incorporation of DAG oil in cakes is fairly straightforward; it can be added either as a partial replacement for shortening or as the oil phase component in a fluid shortening system. If the DAG oil is added as a partial replacement for shortening, it is added at the same stage as the shortening to ensure proper mixing with the shortening and sugar. If the DAG oil is added as the oil component in a fluid shortening, it is typically added in with the sugar to facilitate creaming and subsequent air incorporation before the addition of dry ingredients.

To determine the optimum inclusion rate of DAG oil in cake, a model system should be used. Once the desired inclusion rate has been determined, the effect on flavor and shelf life should be considered. By using a liquid oil to replace part or all of the solid fat originally in the system, perception and release of flavor compounds may be altered; consequently, minor changes may be required to maintain flavor and aroma characteristics. Depending on the level of liquid oil in the system, it may be necessary to alter the preservatives/mold inhibitors, antioxidants, or packaging used to obtain the desired shelf-life characteristics (1,6). Because functional attributes and eating qualities vary depending on the type of cake baked, similar practices would have be used to determine the inclusion level, flavor profile, and storage considerations for other cakes made with DAG oil. To test the concepts illustrated above, work was done using four model cake formulas to examine how DAG oil affected functional properties and flavor profile in each cake type. Model systems were based on both scratch and box-mix formulas to determine the effect of DAG oil on nucleation and formation of air cells in multistage and single-stage mixing processes.

Use of Diacylglycerol Oil in Multi-Stage Mixing (Scratch Formulas)

To determine performance of DAG oil under multistage mixing conditions, a yellow cake formula containing 110% sugar, 45% fat (shortening + oil + emulsifiers), and

100% cake flour was selected as a model system. Because all scratch formulas use the yellow cake formula as a base, it was reasoned that performance differences seen between DAG and TAG oils in 110% sugar yellow cakes would be representative of performance differences seen in other 110% sugar cakes (e.g., white, chocolate). All-purpose shortening was used as the plastic shortening in all trials, whereas either DAG or TAG oil was used as the liquid oil in the trials. Plastic shortening accounted for 50–70% of the fat source used, whereas liquid oil accounted for 30–50% of the fat source used, depending on the trial. To form the fluid shortening for each trial, the liquid oil, plastic shortening, and emulsifiers were creamed together before the addition of the dry ingredients. The remaining mixing steps were identical to those typically used in multistage mixing processes.

Results showed slight differences in volume and texture when DAG oil was used to replace TAG oil in a modified fluid shortening system (Table 22.1). In general, cakes made with DAG oil had lower volume, but had softer texture and were less gummy than cakes made with TAG oil (Table 22.1). Cakes made utilizing 30, 40, or 50% DAG oil to replace all-purpose shortening were 5.5, 5.9, and 3.0% lower in volume, respectively, than cakes made with TAG oil. Slight differences were seen in softness and gumminess scores when 30% DAG oil was used, whereas differences in softness and gumminess scores were more marked at the 50% use levels (Table 22.1).

Although lower volumes usually lead to increased hardness and gumminess values, the difference between expected and actual results was most likely due to differences in polarity between DAG and TAG oil. Increased polarity of DAG oil increased its interaction in the aqueous phase; consequently, when used to encapsulate air cells, segregation of the air cells from the aqueous phase was not as complete as when TAG oil was used. As a result, the air had greater mobility within the aqueous phase before gelatinization of the starch, leading to the formation of larger air cells, resulting in lower volume (2). Although interaction with the aqueous phase resulted in slightly lower cake volumes, it improved the water-holding capacity of the batter, yielding increased softness and decreased gumminess in the finished cake (Table 22.1). At higher inclusion levels of oil, less difference was seen in finished cake volumes between DAG and TAG; in addition, the texture was proportionally softer and less gummy in cakes made with DAG oil (Table 22.1). Improvements in volume are most likely related to higher batter viscosities in the DAG oil treatment, which reduced mobility and subsequent loss of air cells; improvements in texture are most likely related to the improved water-holding capacity of DAG oil relative to TAG oil. Although it is believed that differences in volume between cakes made with DAG and TAG oils would be within the acceptable range of variation for a manufacturer, one could restore volume in cakes made with DAG to levels seen in cakes made with TAG by applying one of the following options: modification of the leavening acid (2), increased level of leavening agents (2,3), small additions of hydrocolloid gums (6), modification of the emulsification system (2), or modification of the mixing conditions (3,6).

TABLE 22.1
110% Sugar Scratch Cakes: Mean and SD for Textural Attributes[a]

% Shortening/ % Oil ratio	Surface volume index units[b]		Hardness (g)		Gumminess		Springiness		Cohesiveness		Resilience	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
70/30 DAG	746.9	14.98	610.85	55.03	475.20	40.43	0.855	0.046	0.778	0.005	0.473	0.006
70/30 TAG	790.7	9.28	699.54	51.72	551.98	39.12	0.908	0.020	0.789	0.013	0.484	0.011
60/40 DAG	780.0	9.30	548.01	81.51	425.96	57.24	0.846	0.130	0.779	0.021	0.466	0.023
60/40 TAG	828.8	6.43	627.76	18.08	477.17	18.69	0.855	0.043	0.760	0.017	0.452	0.019
50/50 DAG	777.1	40.01	509.12	13.31	400.81	12.50	0.899	0.035	0.787	0.006	0.465	0.004
50/50 TAG	801.5	8.68	675.36	24.68	530.32	24.66	0.915	0.036	0.785	0.016	0.483	0.021

[a]For the shortening/oil blends, all-purpose shortening was used as the shortening fraction and either DAG or TAG oil was used as the oil fraction.
[b]Based on AACC Method 10-91. Method was modified to more precisely calculate surface area and account for asymmetry in the product. One surface volume index unit = 0.1 mm^2.

Use of DAG Oil in Single-Stage Mixing (Box Mixes)

Box-mix formulas tested were white, yellow, and devil's food cake. Due to differences in polarity between DAG and TAG oil, white cake was tested to determine whether functionality differed with use of egg whites, yellow cake was tested to determine whether functionality differed with use of whole eggs, and devil's food cake was tested to determine whether functionality differed with addition of cocoa and a lower mixing time. Independent triplicate trials were conducted on each cake type to have sufficient data to determine statistical significance between treatments.

Results obtained for white cake made from single-stage mixing procedures showed no differences in volume, hardness, gumminess, springiness, or cohesiveness between cakes made with DAG and TAG oils (Table 22.2). However, the cakes made with DAG oil were significantly more resilient than the cakes made with TAG oil (Table 22.2). Results indicate that both liquid oils have similar interaction with the emulsifiers and egg whites used in the formula.

Although results were similar when DAG oil was used to replace TAG oil in white cakes, more differences were seen when it was used to replace TAG oil in yellow cakes. Yellow cakes made with DAG oil were significantly harder, more gummy, more cohesive, and more resilient than those made with TAG oil; volume and springiness did not differ in the two treatments (Table 22.2). Because the main difference between white and yellow cake formulas was the use of egg whites vs. whole eggs, it was reasoned that differences in hardness, gumminess, and cohesiveness between the two oils were most likely due to differences in their interaction with egg yolk phospholipids. Because DAG oil has a higher polarity than TAG oil, it can solubilize more of the egg yolk phospholipids, reducing their ability to act as emulsifying and tenderizing agents (9). Consequently, hardness of the cake made with DAG oil increases. Because fewer of the egg yolk phospholipids orient themselves at the interface between water and oil to reduce surface tension and provide emulsification, more are available to participate in interactions with free water, increasing water-holding capacity and gumminess of the cake. Increased gumminess makes the cake more cohesive, causing it to break down in the mouth more slowly. Despite the differences seen in mechanical texture analysis, no significant differences were seen between cakes made with DAG or TAG oils when presented to consumers in a triangle test. Therefore, although some significant differences were detected in the texture of cakes made with DAG and TAG oil, differences were minor as judged by actual consumers of the two products.

Finally, results obtained for devil's food cake made from box mixes showed no differences in volume, hardness, gumminess, springiness, or cohesiveness between cakes made with DAG and TAG oils (Table 22.2). However, cakes made with DAG oil were significantly more resilient than cakes made with TAG oil (Table 22.2). Results indicate that both liquid oils have similar interactions with the emulsifiers and alkalized cocoa used in the formula. Similarity in texture was unexpected, considering the results obtained for DAG and TAG oils in yellow cake. One possible explanation for the observations is that reductions in both mixing speed and time reduced gluten

TABLE 22.2
Box-Mix Cakes: Least Significant Difference Means for Textural Attributes[a]

Cake type	Surface volume index units[b]		Hardness (g)		Gumminess		Springiness		Cohesiveness		Resilience	
	DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG
White	718.7	731.2	454.42	429.8	337.83	308.32	0.947	0.962	0.743	0.717	0.419[a]	0.379[b]
Yellow	860.9	867.3	483.66[a]	373.73[b]	383.72[a]	286.49[b]	0.961	0.959	0.794[a]	0.767[b]	0.472[a]	0.429[b]
Devil's food	748.7	755.6	559.69	544.80	457.71	426.13	0.988	0.975	0.823	0.782	0.503[a]	0.468[b]

[a]Means with different letters for an attribute differ at the 95% confidence level.
[b]Based on AACC Method 10-91. Method was modified to more precisely calculate surface area and account for asymmetry in the product. One surface volume index unit = 0.1 mm^2.

development in devil's food cake compared with yellow cake. Consequently, less tenderization from the egg yolk phospholipids was required; therefore, differences in hardness between devil's food cakes made with DAG or TAG oil were minimal. Because no differences were seen in gumminess or cohesiveness between the DAG oil and TAG oil treatments, the egg yolk phospholipids were most likely interacting with the cocoa particles in the formula. Interaction with the cocoa reduced the amount of phospholipid in the DAG oil; consequently, the water-holding capacity of the DAG oil was reduced to a level similar to that seen in TAG oil, thus minimizing differences in gumminess between the two treatments. Because no difference was observed in gumminess, the cakes disintegrated in the mouth in a similar fashion; therefore, no differences were seen in cohesiveness between the two treatments.

Although some differences between the performance of DAG oil and TAG oil in cakes appear to be dependent upon the particular formulation tested, one parameter that was consistent among all formulation types was resilience. White, yellow, and devil's food cakes made with DAG oil were all found to be significantly more resilient than the same cakes made with TAG oil (Table 22.2). Improved resilience is particularly important for box-mix cakes because these cakes are usually more delicate and susceptible to damage than cakes made from multistage mixing processes (2). Therefore, using DAG oil to replace TAG oil could be advantageous in box-mix cakes.

Use of DAG Oil in Muffins

Muffin formulations are similar to high-ratio cakes; however, they are typically less sweet, use a higher protein flour, and have lower levels of fat than are commonly found in most high-ratio cakes (10). In addition, muffins are more dense and have a chewier texture than their high-ratio cake counterparts (3). Ingredients affecting volume, texture, and eating quality of muffins to the greatest extent are the fat source, flour, eggs, sugar, leavening agents, gums, and starches used (10). Mixing conditions are also important. Typically, muffins use less vigorous mixing conditions for less time than those used in cakes to avoid excessive gluten development from the use of a higher protein flour (11). As in cake, either single-stage or multistage mixing can be used to make muffins (10). Multistage mixing is preferred in commercial settings to obtain maximum air incorporation, resilience, and resistance to breakage. Because it produces muffins with less structural stability than multistage mixing, single-stage mixing is typically used in food service, in-store, or consumer settings in which production conditions are less abusive.

To test the functional properties of DAG oil in muffins, both apple streusel and banana muffins were selected. Both were made utilizing box-mix formulas and single-stage mixing procedures. The apple streusel formula was selected to determine whether differences in polarity between DAG oil and TAG oil affected the suspension of inclusions, whereas the banana formula was selected to determine whether functional properties were altered by high inclusion levels of oil. Independent duplicate trials on each mix were done to have sufficient data to determine statistical significance between treatments. Results obtained for both muffin types showed no differences in volume, hardness, gumminess, springiness, cohesiveness, or resilience between DAG oil and TAG oil treatments (Table 22.3). Therefore, use of DAG oil does not appear to affect suspension of inclusions, texture, or volume differently from TAG oil, even at high inclusion levels of oil. Actual product testing by a consumer panel (triangle test) confirmed that no significant differences were perceived between DAG oil and TAG oil treatments.

Use of DAG Oil in Brownies

Brownie formulations have characteristics similar to both cakes and cookies (12). They are similar to cakes with respect to sugar and egg content, but resemble cookies with respect to shortening and water content. Brownies can be divided into three main types: fudge, cake, and bar (12). For the purpose of this discussion, we will focus on fudge and cake types. Cake brownies have less sugar, more cocoa, more shortening, and less egg than fudge brownies (12). The reduction in sugar allows the gluten to be more highly developed, which gives the brownies light texture, increased volume, and improved tolerance to changes in mixing time (12). In contrast, fudge brownies have more sugar, less cocoa, less shortening, and more egg (12). Corn syrup is added to bind water, creating the characteristic "fudgy" texture (12). Increased sugar and the presence of corn syrup increase water binding by the sugar fraction, which minimizes gluten development and gives the brownies a dense texture and low volume (12). Because minimal air incorporation and gluten development are desired, the batter cannot be mixed for extended periods of time and is not tolerant to changes in mixing time or conditions (12).

Evaluation of Brownie Formulas

Box-mix formulas were tested to determine whether there were differences in texture or flavor between fudge brownies made with DAG oil and TAG oil. Independent triplicate trials were done to have sufficient data to evaluate statistical significance between treatments. Results showed no differences in hardness, resilience, springiness, or cohesiveness between treatments (Table 22.4). However, brownies made with DAG oil were significantly more chewy than those made with TAG oil (Table 22.4). Results can be explained by examining differences in polarity between DAG oil and TAG oils. Increased polarity of DAG oil relative to TAG oil increases its water-holding capacity, which increases gluten development during mixing, thereby changing the texture of the brownie.

Although texture measurements indicated that brownies made with DAG oil were chewier than those made with TAG oil, these results were not confirmed in consumer testing. When brownies made with DAG oil and TAG oil were compared in a triangle test, consumers thought brownies made with DAG oil were less moist, chewy, and flavorful than brownies made with TAG oil. Further analysis of their comments

TABLE 22.3
Box-Mix Muffins: Least Significant Difference Means for Textural Attributes[a]

	Surface volume index units[b]		Hardness (g)		Gumminess		Springiness		Cohesiveness		Resilience	
Cake type	DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG
Apple	250.0	244.5	402.77	390.92	306.88	302.84	0.820	0.856	0.762	0.775	0.436	0.442
Banana	259.0	258.5	499.08	479.37	383.28	365.00	0.922	0.924	0.769	0.762	0.435	0.420

[a]No significant differences were noted in any of the attributes tested.
[b]Based on AACC Method 10-91. Method was modified to more precisely calculate surface area and account for asymmetry in the product. One surface volume index unit = 0.1 mm^2.

TABLE 22.4
Box-Mix Brownies: Least Significant Difference Means for Textural Attributes[a]

Hardness (g)		Chewiness		Springiness		Cohesiveness		Resilience	
DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG	DAG	TAG
967.89	780.72	232.37[a]	209.60[b]	0.530	0.561	0.458	0.481	0.136	0.144

[a]Means with different letters for an attribute differ at the 95% confidence level.

revealed that brownies made with DAG oil were perceived as being slightly more cake-like in texture whereas brownies made with TAG oil were perceived as being slightly more fudge-like. Because fudge brownies are more dense and bind more water than cake brownies, they are likely perceived by consumers as being more moist and chewy (12).

The differences described above were not observed consistently between DAG oil and TAG oil treatments in repeated evaluations. Additional trials comparing the same box mix (from different lots/manufactured at different times) rated DAG oil brownies higher in chocolate flavor than TAG oil brownies. Though DAG oil brownies were rated higher in overall chocolate flavor, the perception of flavor release occurred later than the perception of chocolate flavor in TAG oil brownies. Therefore, although release of chocolate flavor was consistent between treatments, perception of flavor intensity was not. Differences were also seen in texture between different lots of mix tested. Some evaluations rated brownies made with DAG oil as being more chewy and fudge-like, whereas other evaluations rated brownies made with DAG oil as being less chewy and more cake-like. Because differences between texture and flavor seemed to vary with the lot of mix being tested, it was reasoned that lot-to-lot variability between mixes is greater than texture and flavor differences based on the type of oil used.

Use of DAG Oil in Nutritional Supplements

Nutritional supplements encompass a wide variety of products. Because guidelines for this product segment are not clearly defined, for the purpose of discussion in this chapter, we will define nutritional supplements as products specifically designed to meet the health needs of a particular class of patients. Typically, nutritional supplements can be consumed either orally or enterally (13), depending on the health status of the patient. Because the formulations have been balanced to meet the patients' daily needs for protein, carbohydrate, fat, vitamins, and minerals, they may consume nutritional supplements as a partial or complete replacement for food.

Consumption of nutritional supplements can yield a variety of benefits for patients. Clinical studies in cancer patients have shown that consumption of nutritional supplements can reduce weight loss, preserve lean muscle mass, and improve quality of life (14). Benefits are derived from multiple components working in synergy within the formula. Inclusion of eicosapentaenoic acid (EPA) enables metabolism to be more closely regulated, reducing weight loss resulting from metabolic changes caused by the tumor (14). Protein helps the body to build and maintain muscle mass, and multiple fat sources provide a more consistent supply of energy for the body (14). Medium-chain triglycerides (MCT) provide a more readily available energy source for the body, whereas vegetable oils such as safflower and canola provide a more slowly digested fat source; overall digestion/release of energy is more controlled, which enables the product to be digested more thoroughly and to be better tolerated by patients (15), increasing their energy levels and improving their quality of life (14).

Dialysis patients can also benefit from nutritional supplementation. Because they are tightly restricted in their fluid intake, their supplements are more concentrated (16). In addition, levels of protein, fat, and carbohydrate are adjusted to meet their specific needs. For example, lower protein levels compensate for reduced ability to process high protein loads, whereas higher fat levels offset decreased protein intake (16). Both readily digestible and slower digesting fats are used to provide a controlled release of energy into the body. Carbohydrate levels are reduced to avoid complications in hypertriglyceridemic dialysis patients (16).

Another major category of nutritional supplements is for patients with moderate-to-extreme breathing difficulties. In the mildest cases, patients may require periodic assistance in breathing from mechanical ventilation devices; in the most severe cases, patients would require 24-h breathing assistance from mechanical ventilation devices. In mild cases, either oral or enteral feeding would be permitted; in severe cases, feeding would be entirely by enteral means. Formulations are concentrated to provide a nutrient-dense product because patients have a restricted fluid intake. Levels of protein, fat, and carbohydrate are adjusted to provide a low respiratory quotient (RQ) to minimize the amount of carbon dioxide gas retained in the bloodstream (17). Carbohydrate has the most dramatic effect on RQ (raises carbon dioxide level the most), followed by protein, then fat (17). To provide a product with lower RQ to ease patient breathing, lower levels of protein and carbohydrate and higher levels of fat must be used. Higher RQ/levels of carbon dioxide gas in the blood would exacerbate breathing difficulties in patients with milder cases (18) and may result in respiratory failure in patients with more severe cases (19).

Using DAG oil in nutritional supplements is equivalent to using vegetable oils from a processing standpoint. The only issue that may arise by using DAG oil is related to its polarity. Because DAG oil is more polar than TAG oil, it will be more reactive with oxygen if stored in tanks without an inert headspace. Therefore, to avoid oxidation before processing and to ensure the DAG oil is of optimal quality, it will either have to be stored under an inert headspace or at room temperature and used quickly if a modified headspace is not available.

To test the utility of DAG oil in nutritional supplements, soy-based formulas containing either DAG or TAG oils were processed by ultra-high temperature (UHT) pasteurization and stored for 1 wk before descriptive evaluation by trained panelists. The fatty acid profiles of both oils were matched to ensure that differences noted between the two beverages were due to structural differences between DAG and TAG instead of differences in their fatty acid composition. Soy-based formulas were chosen to investigate differences in the ability of the oils to mask soy notes or to reduce astringency. Protein, fat, and carbohydrate represented ~23, 26, and 51% of energy, respectively. This composition most closely resembled beverages used for patients recovering from injury or surgery (16). Results from the descriptive panel showed no major differences in flavor or mouthfeel between the beverages; thus, based on flavor and mouthfeel, DAG oil could be used to be a complete replacement for TAG oil in nutritional supplements. However, depending upon the needs of patients consuming the beverage, partial replacement may be preferred to provide the most desirable fatty acid profile (e.g., supplementation with EPA or γ-linolenic acid).

Use of DAG oil in Meal Replacement Beverages

Like nutritional supplements, many products and formulations exist for meal replacement beverages. The main differences between nutritional supplements and meal replacement beverages are the customer base for which they are designed and their intended use. Nutritional supplements are designed for hospital patients with specific nutritional needs, whereas meal replacement beverages, with the exception of products designed for type II diabetics, are designed for consumption by the general population. Although most nutritional supplements are consumed to gain or maintain weight, most meal replacement beverages are consumed to lose or maintain weight. Because meal replacement beverages do not generally contain as much protein or fat as nutritional supplements, they are not recommended as sole-source nutrition items. In fact, they are designed to replace only 1–2 meals/d.

Although the primary benefits associated with meal replacement beverages are weight loss and weight maintenance, a number of secondary benefits can arise through their consumption. By losing weight (or maintaining a healthy weight), a person typically feels better, both physically and mentally. In addition, the risk for developing obesity-related cancers (20), non-insulin dependent diabetes (type II) (21), and coronary heart disease (22) can be reduced through proper weight maintenance. Because numerous benefits can be derived from weight loss and/or weight maintenance, a number of clinical studies have been done to evaluate the use of meal replacement beverages as a weight loss aid. Studies have been done in overweight individuals, obese individuals, and individuals with type II diabetes. Overweight individuals are classified as those having a body mass index (BMI) of 25.02–29.9 kg/m2, whereas obese individuals are classified as those having a BMI ≥ 30.0 kg/m2 (23). Because individuals with type II diabetes have impaired glucose control (24) and may require a product more closely matched to their individual needs, they were evaluated among both diabetic and nondiabetic treatment groups.

On the basis of the results obtained from the studies surveyed (25–27), it appears that meal replacement beverages can be used as an effective tool for weight loss and weight maintenance in both diabetic and nondiabetic populations. Further, diets incorporating meal replacement beverages and snacks at the start of their weight loss/weight maintenance program appear to have positive effects on blood pressure, serum triglycerides, blood glucose, and insulin levels in overweight and obese individuals. The reduction in insulin levels during consumption of meal replacement beverages and nutrition bars indicates that these products may also be useful to type II diabetics as dietary adjuncts to improve glucose control.

Using DAG oil in meal replacement beverages is equivalent to using vegetable oils from a processing standpoint. As discussed earlier, extra care should be taken when storing DAG oil because it is more reactive with oxygen than TAG oil. To maximize its keeping quality, the DAG oil should either be stored in tanks with an inert headspace or used quickly if an inert headspace is not available. To test the utility of DAG oil in meal replacement beverages, soy-based products containing either DAG or TAG oils were processed by UHT pasteurization and stored for 1 wk before evaluation by trained panelists. The fatty acid profiles of both oils were matched to ensure that differences seen between the beverages were due to structural differences between DAG and TAG rather than differences in their fatty acid composition. Soy-based formulas were chosen to investigate differences in the ability of the oils to mask soy notes or to reduce astringency. Protein, fat, and carbohydrate accounted for ~15, 10, and 75% of energy, respectively. This composition is similar to commercially available soy-based and dairy-based meal replacement formulations. Results from the descriptive panel showed no major differences in flavor or mouthfeel between the beverages; thus, based on flavor and mouthfeel, DAG oil could be used as a complete replacement for TAG oil in these products. However, partial replacement may be preferred to complete replacement to provide the fatty acid profile that best suits the needs of the intended population (28).

Although the study described above showed no major differences between beverages made with TAG or DAG oil, a previous study conducted on a soy milk beverage did show some differences between the oils. The soy milk beverage was less viscous than typical nutritional supplements or meal replacement beverages and used HTST (high temperature, short time) instead of UHT pasteurization. Although descriptive panelists thought the basic tastes of the soy milk beverages (sweet, sour, salty, bitter) were similar, they thought the sample made with DAG oil had directionally lower soy notes and astringency than the sample made with TAG oil. By examining descriptive results from the beverages tested, one can conclude that differences in flavor between products made with DAG and TAG oils will be more strongly influenced by the type of formulation and processing conditions used than by the oil source selected.

Use of DAG Oil in Nutritional Bars

Nutritional bars appeal to a wide variety of demographic and lifestyle groups. Application areas in which they are used include sports nutrition, body building, athletic endurance, women's health, meal replacements, and specialized diets (e.g., high-protein, low-carbohydrate, and balanced nutrition bars). A newly emerging category of nutritional bars are those that have eating qualities that are similar to commercially produced candy bars, but provide some functional health benefit (e.g., weight loss).

The majority of nutrition bars have a fat content of <7 g/serving, with the most popular bars having a fat content of ~5 g/serving. Much of the fat content in these bars is attributed to the chocolate and yogurt coatings covering the bars; thus the use of DAG oil in these bars may be limited to levels of 1–4 g/serving. DAG oil could either be incorporated into the bar center in typical bars before the forming process or into the caramel and nougat fractions of nutritional bars that mimic commercially produced candy bars.

DAG oil could provide several beneficial effects in nutritional bars, from improvements in the nutritional properties of the bar, to improvement in the bar manufacturing process, or improvement in the textural properties of the bars during storage. The biggest issue related to producing acceptable nutritional bars concerns the drying effect that the dry ingredients, especially proteins, have on the bars during storage. This drying effect can typically be minimized through use of proteins that have low water-binding properties in combination with modification of the water absorption properties of the proteins through coating them with a hydrophobic compound such as DAG or TAG oil.

Use of DAG Oil in Sauces, Gravies, and Frozen Entrées

Sauces and gravies are used in a wide variety of products and applications. They add flavor and elegance to almost any dish, transforming them from bland to spectacular in just minutes. They can be used as toppings for pasta, rice, meat, or vegetables and can be either acidic or neutral in pH. Consumers and restaurants have moved toward the use of processed sauces and gravies, often in the form of frozen entrées and prepared meals, to prepare great tasting meals more quickly and conveniently (29). By selecting the appropriate gravy or sauce, the same basic entrée can be tailored to suit a wide variety of tastes and occasions. In addition, gravies or sauces can be formulated to meet specific dietary needs or constraints for kosher, diabetic, or vegetarian meals (29).

Many ingredients are available to provide the desired stability in sauces, gravies, and frozen entrées. Perhaps the most critical ingredient to a successful gravy or sauce formulation is the type of starch selected. Typically, a starch high in amylopectin is preferred in applications in which a long shelf life or freeze/thaw stability is required (30,31). Although amylose is beneficial from a standpoint of binding water, it tends to have a much higher level of retrogradation over time than amylopectin (32).

In addition, freezing and thawing procedures can dramatically affect the appearance and texture of the finished product (32). Fast freezing causes the formation of many small ice crystals within the product, avoiding the destructive effects caused by large ice crystal formation. Fast thawing allows the ice to change to water as quickly as possible, reducing retrogradation and syneresis (2). The selection of appropriate emulsifiers and stabilizers can also improve freeze/thaw stability in frozen products

(33). Because they act to improve freeze/thaw stability by different mechanisms, using a combination of these ingredients in conjunction with starch would most likely provide the greatest protection against syneresis. Emulsifiers enable smaller oil droplets to be formed, facilitating an even dispersion of the oil throughout the water phase of the product and allowing a more stable emulsion to be formed (33), whereas stabilizers, such as hydrocolloid gums, bind free water and provide viscosity in the gravy or sauce.

Processing conditions also influence the appearance and texture of gravies and sauces. The most common method for processing gravies and sauces is to heat the ingredients to 95°C, homogenize the slurry, and hot fill into cans or jars (33). Because the gravy or sauce will be subjected to high heat for long periods of time, a modified cook-up starch is typically used to achieve the desired stability for products made by this process (31). After the retort cycle is complete, the products may either be stored at room temperature in the original cans or jars or used in frozen-food products. Although this process is straightforward and easily done from a manufacturing perspective, subjecting the gravy or sauce to high heat for extended periods of time decreases the contribution in viscosity from the starch (33).

To avoid such losses in viscosity, newer manufacturing facilities process gravies and sauces at lower temperatures. Initial processing takes place at 50°C instead of 95°C; the product is then homogenized in traditional fashion, but sterilized and cooled through the use of heat exchangers before packaging or freezing (33). Heat exchangers heat and cool the product much more rapidly than bulk processing, preserving peak viscosity of the starch. Consequently, sauces and gravies made using this technology are more stable and have a longer shelf life than products made at 95°C (33).

Using DAG oil in gravies and sauces is fairly straightforward; it can be added as a partial, or in some cases, a complete replacement of the shortening, dairy fat, or oil typically used in these products. It is added at the same stage as the fat source typically used to make the product; thus, no specialized processing equipment or handling is required to use DAG oil in these systems. To determine the optimum inclusion rate of DAG oil in the gravy or sauce, a model system should be used. Once the desired inclusion rate has been determined, the effect on viscosity, texture, and mouthfeel should be investigated. By using a liquid oil to replace part or all of the solid fat originally in the system, it may be necessary to use additional stabilizing and thickening agents to produce a product with a viscosity, mouthfeel, and texture similar to the control product. In addition, the effect on shelf life should be considered. Depending on how much liquid oil is incorporated into the system, it may be necessary to use additional/different antioxidants or preservatives to obtain similar shelf-life characteristics. Because functional attributes and desired texture and mouthfeel vary depending on the product being made, similar practices would have to be used to determine the optimum inclusion level, type and level of stabilizing/ thickening agents, and storage considerations for other sauces or gravies made with DAG oil.

To test the concepts illustrated above, work was done using the model systems described:

1. Traditional white sauce made using milk and cream as the fat source. The white sauce contained 7.3% fat and 2.5% modified food starch in the control formula.
2. Modified white sauce made using butter as the fat source. The white sauce contained 7.3% fat, 2.5% modified food starch, and 0.10% xanthan gum in the control formula. In addition, the use and necessity of emulsifiers were investigated using this model system.
3. Traditional brown gravy made using partially hydrogenated vegetable shortening as the fat source. The brown gravy contained 6.1% fat, 3.5% modified food starch, and 0.17% xanthan gum in the modified control formula.
4. Traditional barbecue sauce made using vegetable oil as the fat source. The control formula for the process contained 5.0% fat and 2.0% modified food starch.
5. Meat marinade with 18.6% vegetable oil and 0.20% xanthan gum in the control product.

In all of the systems described, DAG oil was used as a complete replacement for the fat source ordinarily contained within the system. Fatty acid profiles of DAG and TAG oils were matched to ensure that differences seen between the performance of the two oils was due to their structure rather than differences in their fatty acid profiles. Model systems 1–4 were heated to 95°C and cooked for 5 min under continuous agitation. After cooling the samples in the refrigerator for approximately 24 h, viscosity readings were taken at 25 and 50°C to determine the viscosity profile at room temperature and consumption temperature, respectively. Model system 5 was processed at room temperature using moderate, continuous agitation for the entire make-up procedure of the product. Samples were allowed to equilibrate for approximately 24 h before viewing separation behavior in control and test products.

Traditional White Sauce Using Milk and Cream. White sauces were chosen as the first model system to be investigated due to their wide range of use across many different applications. White sauces are typically used as a base to make Alfredo sauce, cheese sauce, curry sauce, and mustard sauce, among others. Because these applications would transcend both home and industrial use, the functionality of DAG oil was investigated from the perspectives of both home and industrial users. Nonfat dry milk and either DAG or TAG oils were added to test formulas to replace the protein and fat ordinarily contributed by milk and cream. Initial formulations containing either DAG oil or TAG oil were less viscous and had a less creamy mouthfeel than the control formulation containing solid fat; however, formulations with DAG oil and TAG oil were comparable to the control when either extra starch or a starch/hydrocolloid blend were used to provide added thickening.

Modified White Sauce Using Nonfat Dry Milk and Butter. Due to variations in viscosity and texture between batches of white sauce controls made with milk and cream, a model system using nonfat dry milk and butter was explored. Because the fat source was the only variable in both control and test formulations, differences in texture, viscosity, and mouthfeel between each fat source could be more clearly identified. In addition, the effect of emulsifier use on the fat sources was tested. Because emulsifiers improve product stability and shelf life, their use would most likely be preferred in commercial applications in which the target shelf life of a gravy or sauce can range from 9 mo to 1 y.

When the white sauces were tested without emulsifiers, equivalent viscosity was measured in products made using either DAG oil or TAG oil at both 22 and 50°C (Figs. 22.6 and 22.7). Both sauces were lower in viscosity than the control (made with butter) (Figs. 22.6 and 22.7), indicating additional starch or a starch/hydrocolloid blend would be necessary to achieve equivalent viscosity and mouthfeel from a liquid oil compared with a solid fat source. When emulsifiers were added at a level of 0.2% (total formula weight basis), viscosity decreased in all cases (Figs. 22.6 and 22.7). When tested at 22°C, comparable drops in viscosity were observed for emulsified sauces made with butter and DAG oil but much higher drops occurred in emulsified sauces made with TAG oil (Fig. 22.6). In contrast, when the viscosity of emulsified and unemulsified sauces was compared at 50°C, little difference was noted between sauces made with butter, similar reductions were noted between sauces made with DAG oil, and the greatest reductions (even more than those seen at 22°C) were noted between sauces made with TAG oil (Fig. 22.7). These results suggest that either DAG or TAG oils could be used to make an acceptable white sauce in applications in which emulsifier usage is not required. However, DAG oil may offer a performance advantage over TAG oil in formulations containing emulsifiers because the viscosity of white sauces made with DAG oil appears to be less affected by emulsifiers than the viscosity of white sauces made with TAG oil. Further, fewer added stabilizers and thickeners would be required to make a product comparable to the control when DAG oil is used, allowing the flavor of the sauce made with DAG oil to be more closely matched to the flavor of the control product.

Traditional Brown Gravy Made with Shortening. Brown gravies were chosen as the second model system to be investigated because they are widely used as a base to make such sauces as Bordelaise sauce, mushroom sauce, Piquant sauce, and Provencale sauce. In these formulations, either DAG oil or TAG oil was added to test formulas to replace the fat ordinarily contributed by shortening in the control formula. Xanthan gum was added to all formulations to provide body and cling to enable the formulation to meet the most diversified set of needs for both home and industrial users.

Results on brown gravies evaluated at room temperature indicated there were no major differences in viscosity between gravies made with shortening, DAG oil, or TAG oil. However, when these same gravies were evaluated at 50°C, the viscosity of the gravy containing shortening was considerably less than that of gravies made with either DAG oil or TAG oil. These differences were most likely caused by the shortening changing from a solid phase to a liquid phase. Because DAG and TAG oils contain very little saturated fat, very little saturated fat was available to undergo a phase

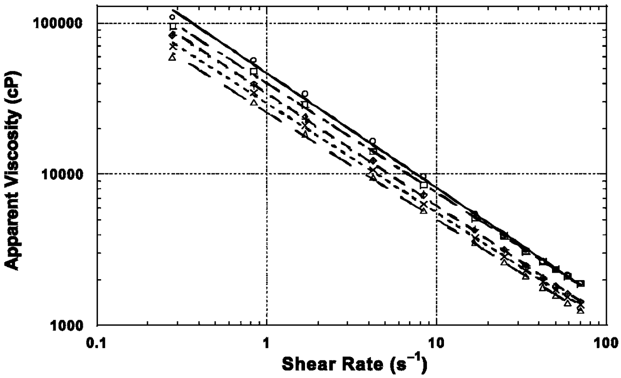

Fig. 22.6. Viscosity profiles of white sauces made with a nonfat dry milk/butter model system. Evaluations were made at room temperature (22°C) on the following fat source/emulsifier combinations: butter, no emulsifier (○); butter, with 0.2% emulsifier (□); DAG oil, no emulsifier (◇); DAG oil, with 0.2% emulsifier (x); TAG oil, no emulsifier (+); and TAG oil, with 0.2% emulsifier (△). Equations for the lines and *r*-squared values are as follows: (○) = 46,597·*x*(–0.75836), *R* = 0.9959; (□) = 40,071·*x*(–0.72404), *R* = 0.99877; (◇) = 34,416·*x*(–0.74449), *R* = 0.99926; (*x*) = 29,497·*x*(–0.72362), *R* = 0.9989; (+) = 33,891·*x*(–0.74173), *R* = 0.99966; and (△) = 25,667·*x*(–0.70888), *R* = 0.99902.

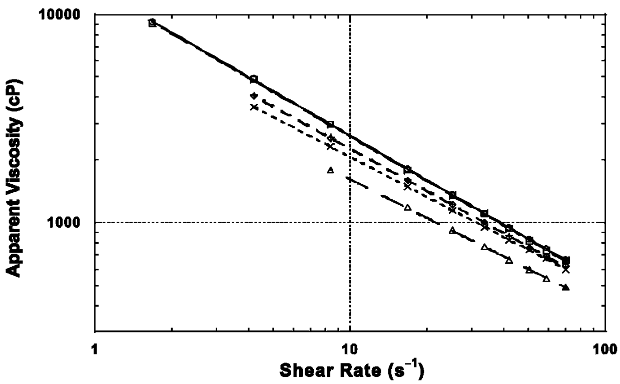

Fig. 22.7. Viscosity profiles of white sauces made with a nonfat dry milk/butter model system. Evaluations were made at consumption temperature (50°C) on the following fat source/emulsifier combinations: butter, no emulsifier (○); butter, with 0.2% emulsifier (□); DAG oil, no emulsifier (◇); DAG oil, with 0.2% emulsifier (x); TAG oil, no emulsifier (+); and TAG oil, with 0.2% emulsifier (△). Equations for the lines and *r*-squared values are as follows: (○) = 13,353·*x*(–0.70738), *R* = 0.99993; (□) = 13,257·*x*(–0.70777), *R* = 0.9999; (◇) = 10,583·*x*(–0.67004), *R* = 0.99998; (*x*) = 8,965.4·*x*(–0.6362), *R* = 0.99998; (+) = 10,787·*x*(–0.67446), *R* = 0.99999; and (△) = 6648.1·*x*(–0.61378), *R* = 0.99992.

change from solid to liquid in either one of these oils; consequently, differences in viscosity were less obvious for the gravies made with liquid oil than the gravy made with shortening. Because 50°C simulates the consumption temperature of the gravy, thicker gravies made using liquid oils may be perceived as being richer, more premium products than gravies made with shortening. These results indicate that either DAG or TAG oils could be used as a complete replacement for shortening with little to no change in processing conditions in the model system tested. By using DAG oil to replace shortening, not only could the level of saturated and *trans* fats be greatly reduced in the gravy, but the product would also have the healthy benefits associated with DAG oil consumption.

Traditional Barbecue Sauce Made Using Vegetable Oil. Barbecue sauce was chosen as the third model system to be investigated to determine whether there were any differences in functionality between DAG and TAG oils in low pH systems compared with neutral pH systems. No major differences were noted in flavor or viscosity between barbecue sauces made with DAG and TAG oils; therefore, DAG oil could be used as either a partial or a complete replacement for TAG oil in the model system tested with no changes in processing or formulation required.

Marinade for Meats Used in Frozen Entrees. The final model system used to evaluate performance of DAG oil in sauce and gravy type products was as a replacement for TAG oil in marinades. Xanthan gum was added to the marinade to provide body, cling, and make it suitable for frozen applications. There were no major differences in flavor or viscosity between marinades made with DAG and TAG oils; therefore, DAG oil could be used as either a partial or a complete replacement for TAG oil in the model system tested with no changes in processing or formulation required.

Summary

Diacylglycerol oil can be used as either a partial or a complete replacement for triacylglycerol oil, depending on the individual product application and characteristics desired. In some cases, DAG oil can even be used as a partial replacement for shortening, reducing the level of saturated and *trans* fat in the end product. By adjusting the ratio of diacylglycerol oil to shortening in cookies, one can create textures ranging from a typical snap type to more of a soft batch–type cookie. Scratch cakes made with DAG and TAG oils had similar volume, but softer textures were noted in cakes made with DAG oil, especially at higher inclusion levels of oil. Box mix cakes made with DAG and TAG oils had similar volume and texture, with DAG oil cakes be statistically more resilient than TAG oil cakes. No significant differences were observed in muffins or brownies made with DAG oil.

Nutritional supplements and meal replacement beverages formulated with DAG oil showed similar or improved flavor profile and mouthfeel compared to those made with TAG oil, depending on the formulation and processing conditions tested. Using diacylglycerol oil in nutrition bars helped retard water absorption by the protein fraction, delaying hardening and improving the shelf life of the bar. DAG oil may be used in high-protein nougats or caramels or as an extrusion aid in these bars. Formulating sauces and gravies with DAG oil reduces the amount of saturated and *trans* fats in the product through replacement of shortening or dairy fat with liquid oil. The flavor profile of products made with DAG oil is similar to the controls made with shortening or dairy fat; however, in some cases, it may be necessary to use additional stabilizers/thickeners in products made with liquid oil (DAG or TAG) to match the viscosity and mouthfeel of the controls made with a more solid fat source.

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