# Investigation into the Performance of Emulsified Liquid Shortenings Containing Palm-Based Hard Stocks

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## INTRODUCTION

In formulating products, food manufacturers are aware of the Food Regulations and customer attitudes toward *trans* fatty acids and saturated fatty acids. A particularly difficult problem for the margarine and shortening manufacturer is to supply functional fats to the baking industry and other food processors. Fats are partly or fully hydrogenated not only to develop the plastic texture that enables them to cream and aerate through the dough or batter but also to veer the crystallization towards β′ to ensure acceptable performance. Examination of liquid shortening shows that it is possible to meet the needs of the baker while lowering the *trans* fatty acid content. A large volume of literature has been published on the manufacture of liquid shortenings and their uses. Much of it cites the negative consequences of promoting β′crystallization during manufacturing as this thickens the product and limits its use.

Stable liquid shortenings can be made by incorporating relatively high levels of palm oil products that crystallize in the β′ form, for a performance better than that of plastic fats or liquid oils for cake batter. The functional properties of the liquid shortening can be enhanced further with selected emulsifiers. Removal of *trans* fatty acids from fat products is difficult for the producer. He may do so for nutritional compliance, but in the process compromise his product performance.

The function of semi-solid fats, termed plastic fats, is influenced by the ratio of liquid to solid (Telloke, 1983) in the lipid phase, and the crystal packing arrangement developed during processing. The crystal form, size and shape must be balanced with careful blending as they are critical for the final application in bakery products. The function of fats in bakery application is well studied. While the traditional baking methods have been modified, the requirements for the functional properties of fats remain. Creaming and emulsifying capacity are of paramount importance - creaming because of its contribution to the baked volume, and emulsification because it controls the moisture and liquid take-up. These latter functions are critical in applications such as cake batter, and emulsifiers are finding increased use to meet the demands for improved performance (Podmore, 1995).

Designing margarine or shortening for a specific bakery application, or product, is a challenge. *Trans* fats, in certain applications and notwithstanding their health risk, actually, offer desirable physical and functional attributes. Often, a shortening is expected to perform in a range of products, and meet varied demands in manufacture, and given its particular plastic range, it may be expected to perform within certain tolerance. Conversely, the same shortening may be expected to satisfy a number of different applications. Removal of *trans* tends to reduce the available options. This point, coupled with the preference to reduce total saturates, makes it all very complicated.

Shortenings are made in a number of formats, but are typically used in the plastic form, often described as *traditional*. Liquid shortenings are generally accepted more as frying media, and general dough fats. Where boxed plastic fats are not used,

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pumpable shortenings have found good application because their solid fat contents (SFCs) tend to be closer to those of traditional boxed shortenings, and have robust tolerance towards *all purpose* applications (Wilson, 2003). The very point of adding fat/oil to cake is to confer moistness, extend its shelf-life and develop a desirable crumb structure. Plastic shortenings can be creamed according to their structure and visco-elastic properties, whereas liquid shortenings do not retain air in the same way as do solid shortenings and so require additional emulsifiers. The presence of liquid oil in the cake batter hinders foaming during whipping and will have a negative impact on cake volume and structure. Again this can be countered with functional emulsifiers.

Liquid shortenings for baking (particularly cake) rely on relatively high levels of emulsifiers, and, historically, have not been much used in Europe (Herzing, 1996). Emulsified liquid shortenings are more accepted in North America. (O'Brien, 1998; Hartnett and Thalheimer, 1979).

The main forms of shortenings used in Europe are boxed/ deboxed fats for the artisan user, and bulk delivered blends which require further plastification before use (Klimes, 1990). There are new trends which challenge the use of plastic shortenings:

- nutritional requirements, and the demands to restrict saturated fatty acids and *trans* fatty acids. The term *hydrogenation* has now to be declared;
- European Union (EU) packaging waste directives; and
- hygiene controls, *i.e*. putting pallets in processing areas.

The purpose of this investigation was to maximize the known advantages of using plastic shortenings - selecting β' tending triglycerides and maintaining crystals in this preferred form in the liquid state. With further enhancement of these liquid systems with emulsifiers, it will be interesting to explore the following:

- can liquid shortenings perform similarly to plastic shortenings?;
- how much emulsifier should be used?;
- what is the effect of using β' promoting hard stocks?; and
- what are the differences in the nutrition profiles between plastic and liquid shortenings?

This paper emphasizes the role of liquid shortenings in cakes and production of a shortening with reduced *trans* acids yet fully able to meet the demands for cake batter.

## EXPERIMENT AND METHODOLOGY

An experiment with two controls was designed to show the range of liquid shortening types. Alpha tending propylene glycol ester (E477), IV = 2 (GRINDSTED™ PGMS SPV) and a distilled alpha monoglyceride (E471) IV = 2 (DIMODAN® HP) were the selected emulsifiers. This emulsifier combination is well documented (Tamstorf *et al.*, 1986). The two controls differed in their physical properties – the first a semi-solid plastic and the second, a liquid. Control 1 was based on a typical low *trans* shortening, and Control 2 a non-emulsified low *trans* liquid shortening. *Table 1* gives the details of the selected oils, emulsifier load and saturated, monounsaturated and polyunsaturated information.

The emulsifiers were tested in liquid oil (rapeseed oil) and a liquid shortening system consisting of hard stock from the following: palm oil, palm stearin, fully hydrogenated palm and Interesterified palm stearin/palm kernel. When palm-based hard stock was melted and blended with liquid oil (Yap *et al*., 1989), sorbitan tristearate, E492 (GRINDSTED™ STS 30) was used as crystallizer to secure and maintain the β' form during slow crystallization. Two emulsifier concentrations were tested giving more chances for the formulated shortenings to approximate various cake batter formulations and meet the legislative guidelines of the European Parliament and Council Directive No. 95/2/EC of 20 February 1995, on food additives other than colours and sweeteners, which state that PGMS (E477) can be used in *fine bakery wares* at a max to 5 g $kg^{-1}$ finished product.

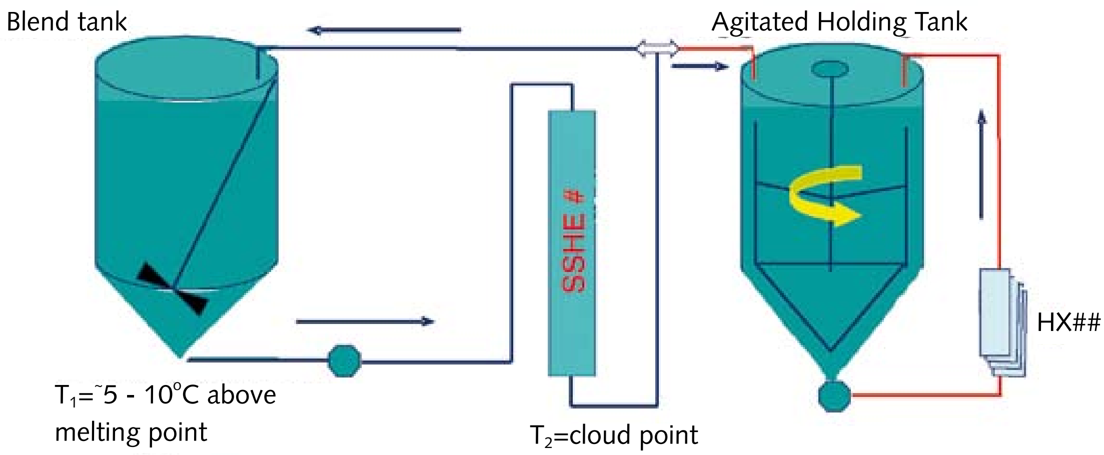
There are numerous ways to produce liquid shortenings (O'Brien, 1998; Widlak, 2001), although they tend to follow similar principles in manufacture, as illustrated in *Table 2* and *Figure 1* for the more common methods of production. Standard scraped surface cooling units can be used to initiate the crystallization – this test used a Gerstenberg 3-tube perfector pilot plant. Once nucleation has begun, the resultant material can be re-circulated back to the blend tank until it reaches the desired equilibrium. *Figure 1* also shows a second option; the cooled nucleated material sent to a slow-moving agitated vessel, with

**TABLE 1. SHORTENING FORMULATIONS**

| Sample | 3847-1 | 3876-1 | 3876-2 | 3847-7 | Control 1 | Control 2 |
|---|---|---|---|---|---|---|
| Base | Oil | Liq. short | Oil | Liq. short | Semi-solid | Liq. short |
| RBD rapeseed oil | 100.0 | 74.5 | 100.0 | 74.5 | 30.0 | 74.5 |
| Palm stearin | - | 5.0 | - | 5.0 | - | 5.0 |
| Interesterified (60% Pst: 40% PK) | - | - | - | - | 30.0 | - |
| RBD palm oil | - | 15.0 | - | 15.0 | 40.0 | 15.0 |
| Hydrogenated palm oil | - | 5.0 | - | 5.0 | - | 5.0 |
| Grinsted$^{TM}$ STS 30 (E492) | - | 0.5 | - | 0.5 | - | 0.5 |
| **Total** | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| **SFC % (p-NMR) including emulsifier** | | | | | | |
| 10°C | 7.0 | 18.0 | 3.0 | 14.0 | 37.0 | 17.0 |
| 20°C | 4.0 | 14.0 | 3.0 | 9.0 | 19.0 | 11.0 |
| 30°C | 3.0 | 9.0 | 2.0 | 7.0 | 7.0 | 6.0 |
| 35°C | 2.0 | 4.0 | 2.0 | 5.0 | 5.0 | 5.0 |
| 40°C | 2.0 | 3.0 | <1.0 | 4.0 | 2.0 | 3.0 |
| Emulsifier | | | | | | |
| Grinsted PGMS SPV (E477) | 8.00 | 8.00 | 4.00 | 4.00 | - | - |
| DIMIDAN HP (E471) | 2.00 | 2.00 | 1.00 | 1.00 | 1.00 | - |
| Shortening dose 12.5% (SpVol) | 3.25 | 3.78 | 3.09 | 3.46 | 3.18 | 2.75 |
| Shortening dose 6.25% (SpVol) | 3.54 | 3.53 | 3.21 | 3.17 | 2.79 | 2.58 |
| Final nutritional incl. emulsifier % | | | | | | |
| Sats. | 15.0 | 28.0 | 11.1 | 24.0 | 42.0 | 21.0 |
| Monos. | 57.0 | 49.0 | 60.2 | 52.0 | 42.0 | 54.0 |
| Polys. | 27.0 | 22.0 | 28.5 | 23.0 | 15.0 | 24.0 |
| *Trans* FA % (FTIR IUPAC 2.207) | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 |

continued agitation allowing the crystal growth to stabilize, until the required holding temperature is reached. Low mechanical shear will affect the crystal size and aggregation, influencing the crystal-to-crystal contact, and finally, the rheological properties. Critically, it is important to establish the cloud point for the selected blend (AOCS Method Test Cc 6-25) because too much crystallization prior to any *tempering* by agitation will cause a premature increase in viscosity, or worse, even gel formation. (Wassell, 2006).

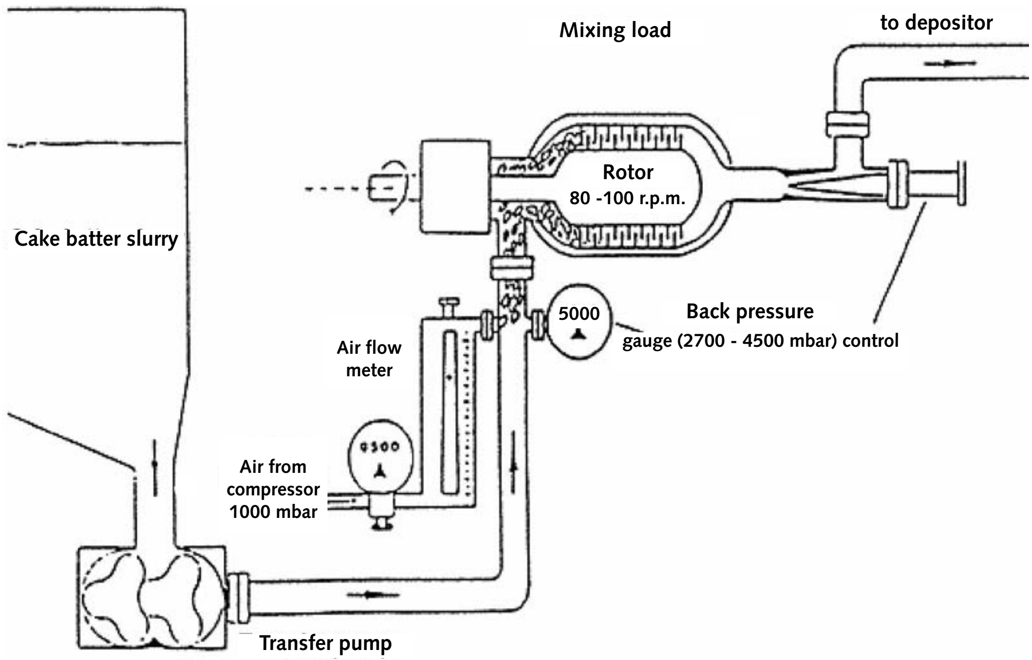
The process time will depend on the mass, blend and finishing temperature. *Figure 1* also shows another way with a heat exchanger attached and the circuit looped to the final holding vessel to help stabilize and condition the crystal network. The process was carried out according to the operational conditions in *Table 2*. The availability of solid fat and its solubility in the liquid oil will affect the available solid fat in crystallization. The materials were first charged into the blend tank, then passed to the Gerstenberg 3-tube perfector pilot plant. The filling-in temperature was controlled using a 3-litre stainless steel water jacketed flask, agitated at 30 rpm for 4 hr. The temperature was then lowered by 1°C every 15 min until the target temperature of 18°C – 20°C. The product was stored for a minimum seven days before use in the baking trials.




Note: # SSHE. Scrape Surface Heat Exchanger
## HX. Heat Exchanger

*Figure 1. Schematic illustration of typical process options for liquid shortening manufacture.*

Cake batters were prepared by mixing *all-in* cake slurries for 1 min in a Hobart N-50 (5L Bowl) planetary mixer. The batter was then transferred to the pilot scale Oakes Mondo type mixer (VS-05 (P13361) at the max rate of 50 litre $hr^{-1}$, and mixing speed of min 140 to max 1400 rpm. The pilot scale mixer employs high speed and pressure mixing as shown in *Figure 2* instead of the standard planetary mixing. Several 350 g batter units from the mixer were baked at 180°C for 45 min. Their specific volumes were measured using an ultrasonic measuring device - TexVol BVM-3. Cake batter images were taken using a Leica TCS SP2 Confocal laser scanner fitted to a Leica DM IRE2 inverted microscope (Leica Microsystems, Germany). The system had three lasers and four detector channels, including a transmitted light detector. With this imaging technique, it was possible to show how and where




Source: Campden Chorleywood Food Research Association (CCFRA), UK.

*Figure 2. Schematic illustration showing the method of aeration for* all-in *cake batter slurry.*

**TABLE 2. SELECTED PROCESS VALUES USED ON GERSTENBERG 3-TUBE PERFECTOR PILOT PLANT**

| Oil phase | 70°C |
|---|---|
| Capacity (kg $hr^{-1}$) | 120 |
| Cooling ($NH_3$) tube 1 temperature (°C) | 5°C -10°C |
| SSHE tube speed (rpm) | 600 |
| Pin machine volume (litre) | 1.0 |
| Pin machine speed (rpm) | 250 |
| Outlet temperature (°C) | ~ 35.0°C |

the selected shortenings were functioning (fat stained Nile red, protein/starch/gluten stained green FITC (Flourescein 5-isothiocyanate), dark areas were gas/air bubbles. Image size 375x375 um). SFC was measured by the IUPAC 2,150 method. The cloud point, according to AOCS method Cc 6-25, was used to determine the exit temperature from the 3-tube Gerstenberg pilot plant using a bright field polarized light microscope - AXIOSKOP 451485 from Carl Zeiss - with an Olympus DP 10 camera. The specific volumes of the cakes were measured with a UV Volumemeter: BVM-L370, from TexVol Instruments, Sweden. A Mondo mixer - VS-05 (P13361) max 50 $litre^{-1}$, mixing head: min 140 - max 1400 rpm $hr^{-1}$ - was used to finish and condition the cake batters. A Brookfield HB DVII instrument, from Fullbrook systems, was used to measure the viscosity of the liquid shortenings.

## CAKE FORMULATION DESIGN

The selected cake batters used contained 12.5% and 6.25% shortening to be within the EU limit of PGMS (E477) (*Table 3*). However, the formulations did not allow for moisture loss during the subsequent baking, so possibly over concentrating the PGMS. The recipes used were based on high ratio cake systems, with relatively high sugar and liquid-to-flour. Noteworthy is the difference between the cake batter formulations. In a typical cake batter, up to 20% plastic shortening can be used. This investigation used liquid systems because they are able to disperse throughout the cake batter very efficiently. Where liquid shortening is used, the cake batter is stressed by the reduced shortening contribution, and by the addition of more liquids and sugar. Egg confers moistness to cake, but was reduced to minimize aeration.

**TABLE 3. *ALL-IN* CAKE BATTER FORMULAE WITH LIQUID SHORTENING**

| Cake formulation (all-in) | % | 3 000 g |
|---|---|---|
| Cake flour, Albatros | 25 | 750 |
| Caster sugar 400/250, Danisco 47507 | 29 | 870 |
| Baking powder, Brentag BPHS 291/5, 403424 | 0.7 | 21 |
| Past. liq. whole egg | 16 | 480 |
| Shortening | 12.5 | 375 |
| Water | 16.8 | 504 |
| **Total** | 100.00 | 3 000.0 |

| Cake formulation (all-in) | % | 3 000 g |
|---|---|---|
| Cake flour, Albatros | 25 | 750 |
| Caster sugar 400/250, Danisco 47507 | 30 | 900 |
| Baking powder, Brentag BPHS 291/5, 403424 | 0.7 | 21 |
| Past. liq. whole egg | 18.5 | 555 |
| Shortening | 6.25 | 187.5 |
| Water | 18.5 | 556 |
| **Total** | 100.00 | 3 000.0 |

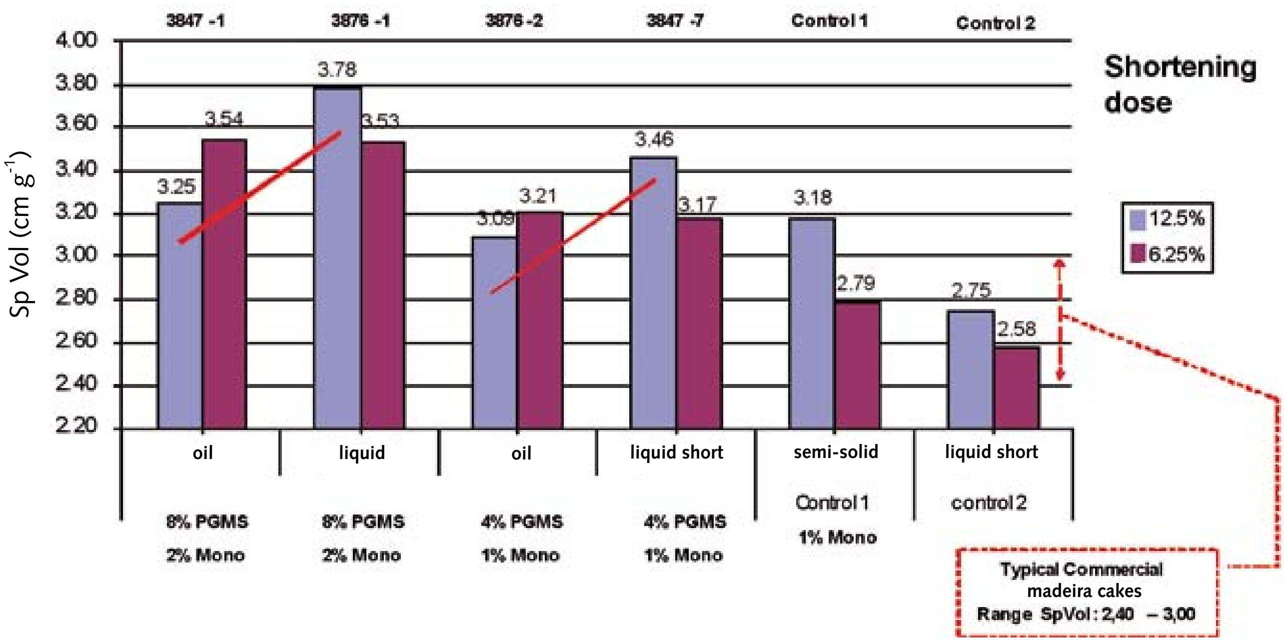



*Figure 3. Effect of emulsifier level and hard stocks on Sp Vol in liquid shortening.*

The addition of more water to the formulation will raise the moisture content of the cake.

## RESULTS AND DISCUSSION

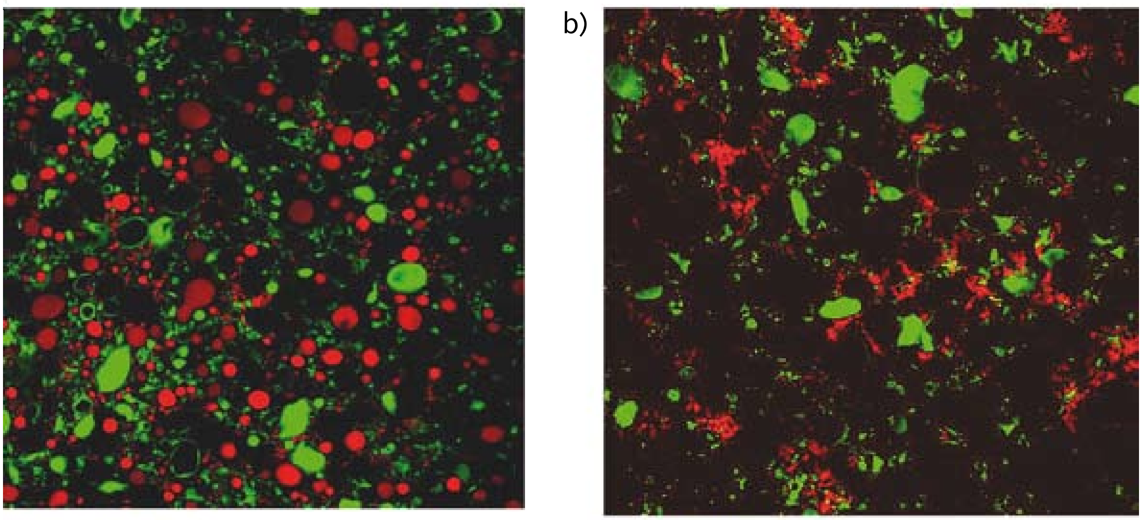
*Figure 3* shows a high emulsifier dose (left) and a non-emulsified liquid (right) shortening. Where liquid shortening (liquid oil plus hard stocks) is 12.5%, there is an increase in the specific volume over that conferred by a standard liquid oil carrier. If the shortening is decreased to 6.25%, the opposite effect is seen - the best volume is obtained with low liquid oil carrier. This has been partly explained earlier - that liquid oil destabilizes protein.

Observation of cake batters using confocal laser scanning microscopy (CLSM) shows the effect of emulsifier concentration

3847-1 @ 12.5%
8% PGMS+2% Mono-di

3876-2 @ 12.5%
8% PGMS+1% Mono-di

a) b)



Sp Vol : 3.25 $cm^3 g^{-1}$

Sp Vol : 3.09 $cm^3 g^{-1}$

Note: Fat stained Nile Red, protein/starch/gluten stained green (FITC), dark areas are gas/air bubbles. Image size 375 x 375 um.

*Figure 4. Effect of emulsifier concentration in liquid oil (a and b).*

on the liquid oil (*Figures 4a* and *b*). With sufficient alpha-tending emulsifiers (8% PGMS) and addition of a second surfactant (2% distilled monoglyceride), a solid film develops at the oil droplet interface (*Figure 4a*) to form a stronger film than in PGMS at the same concentration, thereby preventing inhibition of foam formation. A less concentrated emulsifier system (4% PGMS + 1% Mono) does not allow discrete oil droplets to form as coalescence occurs (*Figure 4b*), resulting in a destabilizing effect. The solid film at the oil-water interface effectively *encapsulates* the oil when air is incorporated during mixing, thus preventing contact with the proteins from egg and flour, which contribute to foam formation. Destabilization is then minimized or prevented (Stauffer, 1999).

The presence of β' hard stocks is characterized (Hoerr, 1960) by the strongest peaks, 3.79 Å and 4.17 Å, in the liquid shortening. As stated earlier, the ratio of liquid-to-solid within a plastic fat is important for mechanical aeration. Fat crystals can only move and align tangently around the gas bubble when the ratio of liquid-to-solid is within the optimum range.

The viscosity of samples from Control 2 was measured from 700 cps to 4500 cps using a Brookfield DVII viscometer. The measurements were taken over a period of two months (*Table 4*). It should be noted that the absence of sorbitan tristearate in Control 2, or liquid shortenings containing a significant amount of palm oil, will result in a rapid viscosity increase within one week from manufacture. The resultant material will then be physically like soft petroleum gel, and lose its liquidity. It is established that the preferred crystal polymorph is beta (β) (Widlak, 2001; Thomas, 1978) and β' should be avoided because the spatial packing of the latter will increase the viscosity. Patents have clearly highlighted this point (Gillies, 1974). However, some evidence suggests the possibility of maintaining the β' form (Podmore, 1995), with functional benefits to be obtained in cake batter. Sorbitan tristearate is effective as a crystal inhibitor in margarines. It is assumed that the β' crystal fat network accommodates sorbitan tristearate and that stearic hinders formation of the more densely packed beta-crystal form (Krog, 1977).

The solid fat content (p-NMR Brucker) results of 3847-7 and 3876-1 are both interesting compared to Control 2 (non-emulsified liquid shortening) because there is apparent suppression of the solids. The 5% addition of PGMS/mono decreased the SFC against that of Control 2. The 10% PGMS/mono maintained a similar solids profile to Control 2. It would seem that the alpha-promoting PGMS may have caused a *eutectic* behaviour (*Table 1*). Further examination may confirm this hypothesis.

Viewed under polarized light (*Figure 5*), it was possible to see crystal-to-crystal flocculation, and it might be assumed that London-van der Waals forces were maintaining the network structure. Where a sufficient balance of β' polymorph is present, a similar plastic shortening behaviour is observed in cake batter. Comparing the CLSM of plastic shortening (Control 1 + 1% mono) in *Figure 6a* with that of a non-emulsified liquid shortening

**TABLE 4. VISCOSITY OF LIQUID SHORTENINGS (Control 2) CONTAINING PALM OIL (Brookfield Viscometer DVII; Spindle No. HB2)**

| Day of manufacture (DOM) | DOM | DOM + 7 days | DOM + 16 days | DOM + 48 days |
|---|---|---|---|---|
| Sorbitan tristearate dose | 0.5% | 0.5% | 0.5% | 0.5% |
| Holding temperature (°C) | 16.8 | 14.9 | 15.0 | 14.9 |
| Spindle speed 10 rpm | | | | |
| Viscosity (cps) | 1 760 | 2 000 | 3 700 | 4 540 |
| Torque (%) | 5.5 | 6.2 | 11.5 | 15.0 |
| Spindle speed 100 rpm | | | | |
| Viscosity (cps) | 690 | 750 | 1 040 | 1 550 |
| Torque (%) | 18.8 | 23.2 | 32.0 | 48.2 |

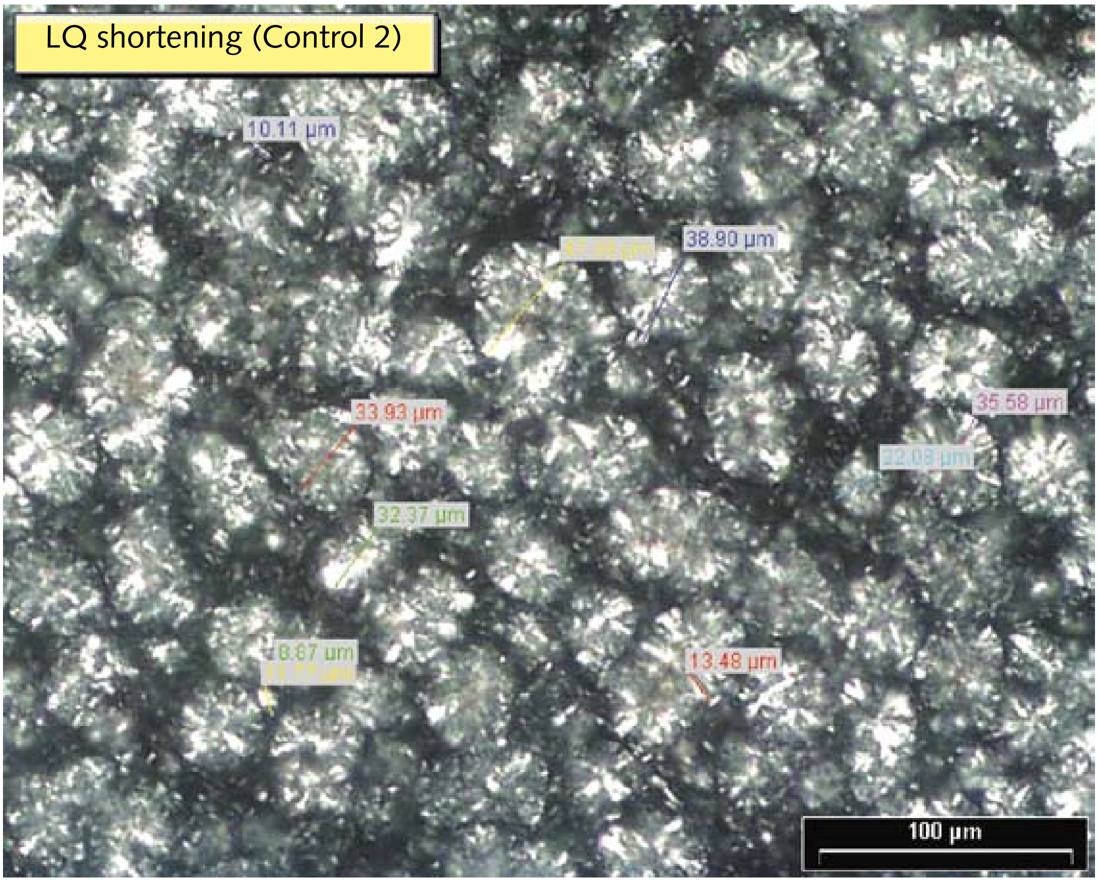



*Figure 5. Polarized light microscopy of non-emulsified liquid shortening.*

(Control 2) in *Figure 6b* shows the crystallized fat to be lipophillic towards the air/moisture interface.

In the example with 12.5% shortening in cake batter, weight-for-weight, the liquid shortenings, 3876-1/3847-7, contributed less liquid oil than did 3847-1/3876-2. The liquid shortening system not only acted as a carrier system for the emulsifier, but also offered functionality and contributed to aeration due to the palm oil components. At 6.25% shortening, the liquid oil system produced a similar volume to the liquid shortening at the same emulsifier concentration. The net overall effect of the emulsifier concentration and liquid oil reduction to 12.5% in the cake batter minimized the impact of destabilization. The CLSM images show, when comparing the same emulsifier concentration - *Figures 7a* to *b* in liquid oil to liquid shortening, that additional solid fat in the shortening enhanced performance, forming a very clear fat film around the air/moisture interface. (Also compare *Figures 4a* to *8b*).

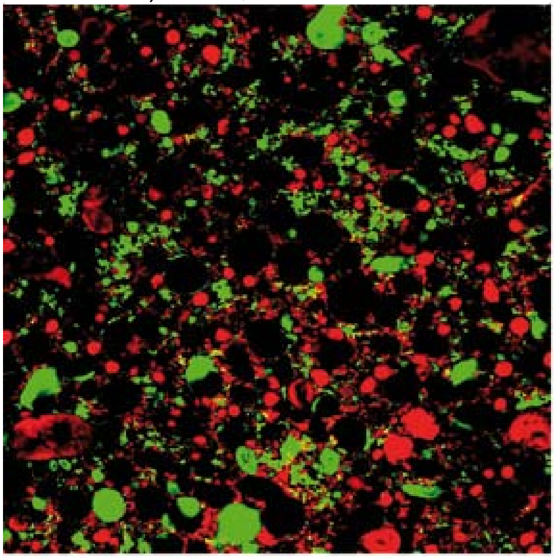
More interesting is the effect of emulsifier concentration in the liquid shortening, because CLSM showed that the concentrations of 8% PGMS + 2% mono, and 4% PGMS + 1% mono, had similar behaviour in cake batter. *Figures 8a* and *b* show that sample 3847-7 has 50% less emulsifier load than 3876-1, and while the addition of β' stable palm components, in themselves, are not emulsifying, they are, however, stabilizing. Referring back to *Figure 3*, there is a marked increase in the specific volume where the emulsified liquid shortening is compared to emulsified liquid oil carrier at the same emulsifier concentration and same inclusion level in the cake batter system. A direct positive effect was observed not only from the emulsifier concentration, but also from the presence and influence of the β' crystal polymorph. Within the scope of this investigation, it seems advantageous to use whole, or components of, palm oil to enable the sufficiently complex fatty acid mixtures to secure the β' crystal form.

## CONCLUSION

Inclusion of β' promoting hard stock (palm oil) in liquid oil to form liquid shortening was beneficial in increasing the specific volume of the cake. In our example of inclusion of 12.5% shortening, the liquid shortening system allowed for a reduction in the emulsifier load. 4% PGMS + 1% distilled mono in the liquid shortening system was

Control 1 (semi-solid shortening, contain a 1% distilled mono) @ 12.5%

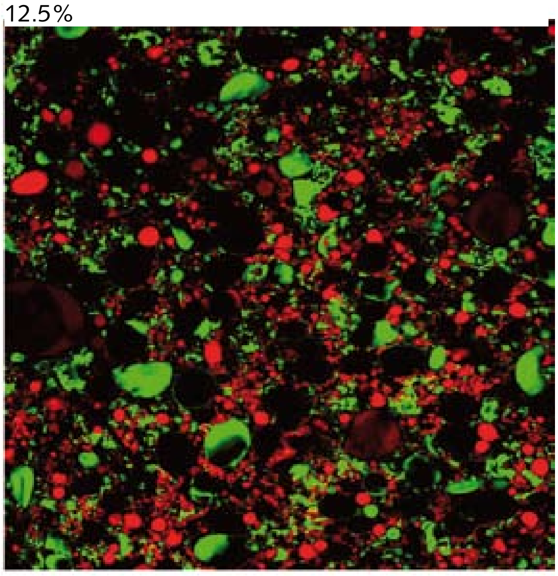
a)



Sp Vol : 3.18 $cm^3 g^{-1}$

Control 2 (non-emulsified liquid shortening) @ 12.5%

b)



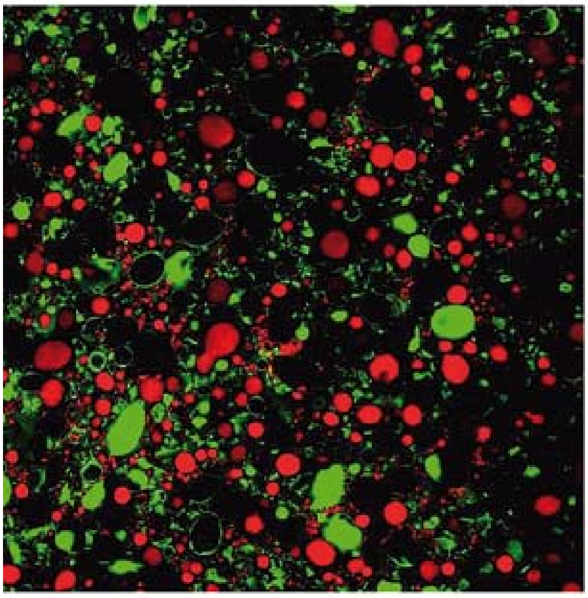
Sp Vol : 2.75 $cm^3 g^{-1}$

Note: Fat stained Nile Red, protein/starch/gluten stained green (FITC), dark areas are gas/air bubbles. Image size 375 x 375 um.

*Figure 6. CLSM comparing plastic and liquid shortening (a and b).*

3847-1 @ 12.5%
8% PGMS+2% Mono-di within liquid oil

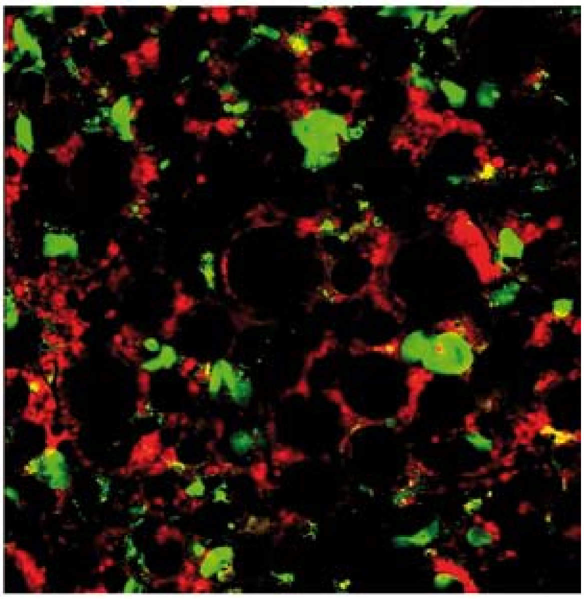
a)



Sp Vol : 3.25 $cm^3 g^{-1}$

3876-1 @ 12.5%
8% PGMS+2% Mono-di within liquid shortening

b)



Sp Vol : 3.78 $cm^3 g^{-1}$

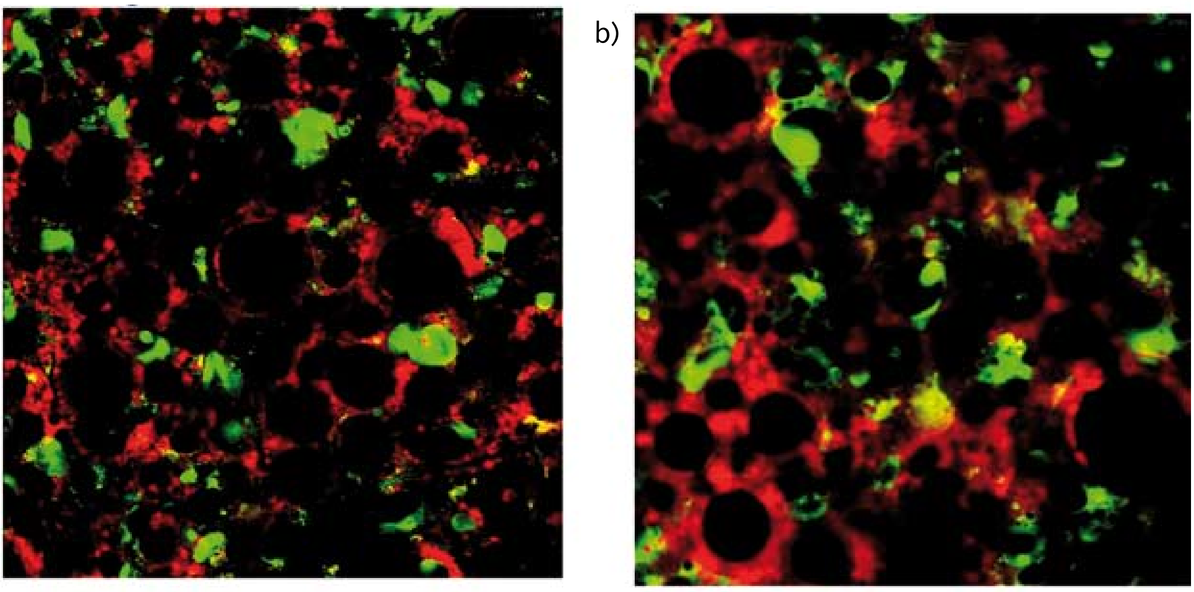
Note: Fat stained Nile Red, protein/starch/gluten stained green (FITC), dark areas are gas/air bubbles. Image size 375 x 375 um.

*Figure 7. CLSM shows effect of emulsifier in oil and liquid shortening (a and b).*

3876-1 @ 12.5%
8% PGMS+2% Mono-di within liquid shortening

3847-7 @ 12.5%
4% PGMS+1% Mono-di within liquid shortening

a) b)



Sp Vol : 3.78 $cm^3$ $g^{-1}$

Sp Vol : 3.46 $cm^3$ $g^{-1}$

Note: Fat stained Nile Red, protein/starch/gluten stained green (FITC), dark areas are gas/air bubbles. Image size 375 x 375 um.

*Figure 8. Effect of emulsifier concentration in liquid shortening (a and b).*

as effective as 8% PGMS + 2% distilled mono in liquid shortening containing palm oil. No negative impact was observed on crumb firmness.

Liquid oil used to carry emulsifier (Hartnett and Thalheimer, 1979) can confer benefits to the specific volume when dosed at 6.25%. There was a marked and faster increase in the cake firmness compared to a shortening dose of 12.5% (data not shown). It is considered likely that while the higher concentration of shortening and, hence, emulsifier, stabilized the batter, at the lower dose (6.25%), the egg/protein-based aeration took over to contribute the most to aeration.

The liquid shortenings demonstrated a functionality to decrease the shortening contribution with sufficient levels of solids – mainly β' tending – in commercial cake application. The examples tested also demonstrated that it was possible to reduce the emulsifier concentration.

This investigation also showed that it is possible to meet the increasingly exact nutritional requirements by lowering the saturated fats by approximately 50% from standard commercial boxed shortening (Control 1) and the *trans* fats content as well.

The combination of palm oil components and selected emulsifiers in a liquid shortening delivery system allowed the functional materials to disperse more efficiently than in a typical solid shortening, and, therefore can be applied to food systems such as cake batter, to enable less total fats to be used in their formulations.

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