Jet-Cooked High Amylose Corn Starch and Shortening Composites for Use in Cake Icings

Mukti Singh and Jeffrey A. Byars

Abstract: Butter cream is an all-purpose icing that is used to both ice and decorate cakes. Cream icings contain up to 40% shortening. As consumers become aware of the need to reduce fat in their diet, the demand for healthy, flavorful, and low-fat food increases. High-amylose corn starch was cooked in an excess-steam jet cooker in the presence of oleic acid. Amylose formed helical inclusion complexes with the fatty acid. Shortening was added at different levels to jet-cooked starch. The resulting starch-lipid composites (SLC) had 0%, 8%, 16%, and 24% fat. The composites were used to substitute shortening in the preparation of cake icings with 1% to 13% fat. SLC icings were formulated by either keeping the total solids constant, or the starch and sugar to water ratio constant as the fat level was reduced. The effect of fat and formulation of shortening and SLC icings on the physical and rheological characteristics were studied. It was found that low-fat SLC icings can be prepared by optimizing the formulation.

Keywords: amylose–oleic acid complex, cake-icing, low-fat, rheology, starch–oil composite

Practical Application: This study indicates potential new applications for SLC that benefit the confectionary industry by generating new products offering healthy alternatives to the consumers.

Introduction
A wide variety of spreadable semisolid products are used to decorate baked goods. These products, known as icings, are made with fat and sugar. Such icings exhibit a rich and creamy mouthfeel due to the high levels of fat. The fats commonly used are butter, margarine, and hydrogenated oils and fats. Commercially, either icings are prepared in the bakery where they are used or ready-to-spread frostings are prepared for use by consumers at home. These icings contain up to 25% fat. There is an increased demand for low-fat healthy, flavorful foods by consumers, who want to reduce fat in their diet as they become increasingly aware of health, disease prevention, and nutrition, but are not prepared to completely give up their favorite foods, like decorated cakes and other baked goods.

There are no standards for formulation and there are a very limited number of scientific papers on the formulations and quality characteristics of icings. Laneuville and others 2005 evaluated the quality of whey-protein isolate xanthan gum complexes (WPXC) as a fat replacer and optimized the suitable amounts of WPXC in cake frostings.

Composites made by jet-cooking starch and lipids in the presence of excess steam form stable suspensions of microscopic lipid droplets in a starch dispersion or gel, having the outward appearance of the cooked starch product but incorporating valuable properties of the included oil phase gel (Fanta and Eskins 1995; Eskins and others 1996; Eskins and Fanta 1997, 1999). Such starch-lipid composites (SLC) have been used to replace fat in food products as they impart functional properties of texture and viscosity from the starch component and taste characteristics and mouthfeel from the lipid component (Byars 2003; Garzon and others 2003a, 2003b; Singh and Byars 2009, Singh and Kim 2009). The lipid component in SLC can be varied depending on the end-use. Vegetable oil, butter, shortening margarine, and tallow are examples of lipids that can be used in the preparation of SLC. High-amylose corn starch cooked in an excess-steam jet cooker in the presence of oleic acid forms helical inclusion complexes with fatty acid. If sufficient oleic acid is used to complex all of the amylose, the cooled product does not form a gel. Furthermore, this method allows oil contents up to 4 times the starch weight in SLC (Byars and others 2008). The objective was to develop and characterize low-fat icings made using SLC instead of shortening. Combinations of liquid and freeze-dried SLC having different levels of fat were used to obtain a wide range of fat content in the resulting icings. Appropriate methods were designed to test the characteristics of icing due to the lack of the available literature.

Materials and Methods
Starch-lipid composites
High-amylose corn starch (AmyloGel 03003, containing approximately 70% amylose; Cargill, Hammond, Ind., U.S.A.) was mixed with oleic acid (Fischer Scientific, Fair Lawn, N.J., U.S.A.) (12% by starch weight) and distilled water. This slurry was passed through a Penick and Ford laboratory Model jet cooker (Penford Corp., Cedar Rapids, Iowa, U.S.A.) under excess steam conditions. The temperature in the hydroheater was 140 °C, the steam
back pressure was 380 kPa (40 psig), and the steam line pressure from the boiler was 550 kPa (65 psig). The cooked product was collected, melted shortening (Crisco, J. M. Smucker Co., Orrville, Ohio, U.S.A.) was added, and the mixture was passed again through the jet cooker under the same conditions. The starch and shortening weights were determined such that each final product contained approximately 8 dry wt% starch and 24%, 16%, or 8% shortening. The products were cooled rapidly in an ice bath while being stirred. The cooled products were either used in their liquid form or freeze-dried.

Icing preparation

For the lack of a standard icing formulation, the control (shortening) icing was optimized with shortening, sugar, and water such that its melting profiles were similar to a popular commercial ready-to-use frosting. A series of icing samples were prepared by blending sugar (powdered cane sugar) into decreasing amounts of shortening; optimum water was added to obtain desired consistency during mixing. The formulation for this shortening series sample is presented in Table 1. Test samples were prepared by blending sugar with liquid and freeze-dried composites containing different levels of shortening. Constant starch to sugar to water ratio series of icings (samples 11 through 18) were prepared by blending combinations of liquid SLC containing 24%, 16%, and 8% shortening and freeze-dried composites containing 16%, 8%, and 0% shortening with sugar such that starch to sugar to water ratio remained unchanged (4.3:68:15), resulting in icings with 1% to 10% fat. Reducing the fat in the constant starch to sugar to water ratio icings resulted in an increase in water content and lowering of the solids in the samples. This could affect the characteristics of the icings. So icing with a constant solid content icing series (samples 21 through 28) were prepared by blending liquid and freeze-dried composites such that all samples in this series had 17% SLC solids (fat and starch), and a moisture content of 15%, 68% sugar was added to all samples in the series.

Physical characteristics

Color was measured using a LabscanXE Hunter colorimeter (Hunter Associates Laboratories Inc., Reston, Va., U.S.A.), and Universal software version 4.01, and reported as L∗, a∗, and b∗. In this color space, L∗ represents the lightness, and a∗ and b∗ are color coordinates, where +a∗ is red direction, −a∗ is green direction, +b∗ is yellow direction, and −b∗ is blue direction (Francis and Clydesdale 1973). Water activity, the availability of water molecules to enter into microbial, enzymatic, and chemical reactions as an indication of its storage life, was measured using an Aquablock 3TE (Decagon Device, Inc., Pullman, Wash., U.S.A.) and reported as aw (Labuza and others 1976; Prior 1979).

Icings were added to a known volume container using an icing bag with a wide tip to ensure uniform fill for all samples. The density of icing was calculated by weighing icing in a known volume container and reported as g/mL.

The refractive index of the icings was calculated using an AR200 Refractometer (Reichert Opthalmic Instruments, Depew, N.Y., U.S.A.) and reported as degree Brix (“B”).

Rheology

Measurements in small amplitude oscillatory shear flow were conducted on an ARES (TA Instruments, New Castle, Del., U.S.A.) controlled strain fluids rheometer. Tests were performed with 25 or 50 mm diameter parallel plates at strains within the linear viscoelastic region for all samples. The linear viscoelastic properties were measured at frequencies of 0.1 to 100 rad/s as the temperature was increased. The edges of the samples were covered with mineral oil, and humidity covers were used to prevent drying of the samples during heating. The yield stress was measured at 25 °C with an AR2000 (TA Instruments, New Castle, Del., U.S.A.) controlled stress rheometer using 40 mm diameter crosshatched steel plates.

Table 1—Composition of shortening and SLC icings.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Fat in prepared icing (%)</th>
<th>Fat in liquid SLC (%)</th>
<th>Fat in freeze-dried SLC (%)</th>
<th>Starch (%)</th>
<th>Sugar (%)</th>
<th>Water (%)</th>
<th>SLC solids (%)</th>
<th>Total solids (%)</th>
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A continuously increasing stress from 1 to 3000 Pa was applied to the sample until it began to flow.

Texture
Icing samples were weighed and stored uncovered at ambient temperature for 10 d. The samples were weighed to determine the moisture loss and the crust texture at 0, 1, 2, 4, 6, 8, and 10 d. Crust hardness was measured as the maximum force of penetration by a 25 mm diameter acrylic probe (P/25P) at a speed of 1 mm/s to a depth of 30 mm using a TA.XT2i texture analyzer (Texture Technologies Corp., Scarsdale, N.Y., U.S.A.).

The spreadability of icings was measured at room temperature with a TA.XT2i texture analyzer (Texture Technologies Corp.). Samples were loaded into a female 45° cone, and a matched male cone (P/45C) was lowered into the sample at 3 mm/s, and then retracted at a speed of 3 mm/s. Consistency was measured as the positive area of force–distance plot material and reported as g mm. Consistency is an important characteristic for the spreadability of the icings on baked goods.

For decorating baked goods, icings are piped onto products using different decorative tips. The ease with which it flows out of the piping bag and its ability to retain its form are important attributes of icing to the decorator. These attributes were measured at room temperature with a TA.XT2i texture analyzer. Samples were loaded in a forward extrusion cell (HDP/FE) having a disc with a 3 mm opening. The average force required for 30 mm of icing to pass through the opening at a speed of 1 mm/s was measured and reported. All tests were conducted at ambient temperature.

Moisture loss during storage
Icings were added to a known weight and volume container using an icing bag with a wide tip to ensure uniform fill for all samples. The samples were stored at ambient conditions. The weight of icing samples was noted at 0, 1, 2, 4, 6, and 8 d of storage. The moisture loss was calculated based on the initial weight (day 0) of the icings.

Statistical analysis

Statistical analysis was conducted using the statistical analysis system (SAS Inst., Inc., Cary, N.C., U.S.A.). Analysis of variance (ANOVA) was used to establish the effect of formulation series (shortening, constant starch to sugar to water ratio, and constant solids content) and fat content in liquid and freeze-dried SLC in icings. Proc GLM and Duncan multiple comparisons test was used to detect significant differences between treatments. Statistics are reported at a significance level of 0.05.

Results and Discussion

Physical characteristics
The control-icing sample had a fat content of 21.5%, which is within the range of commercially available ready-to-spread frostings/icings. An earlier study used a full-fat control containing 320 g/kg of vegetable shortening and 679.4 g/kg sugar (Laneuville and others 2005). Shortening icings having 5% to 22% fat content were used as a control series to study the effect of SLC and formulation on the icings.

Water activity (aw) is one of the most critical factors in determining quality and safety of the foods. Water activity affects the shelf life, safety, texture, flavor, and smell of foods. The water activity of shortening icings ranged from 0.84 to 0.85. The fat content of icings did not have a significant correlation (R^2 = 0.3) with the water activity of the shortening samples. The refractive index of shortening icings with 5% to 22% fat ranged from 70.5 to 74.4 °B. Fat content had a direct correlation (R^2 = 0.6) with the refractive index of shortening icing samples. The color of the shortening samples as determined by the lightness (L^∗), redness (a^∗), and yellowness (b^∗) was not affected by the decrease in the total fat of the icing samples. Density, an indicator of air whipped into the icing, ranged from 1.1 to 1.3 g/mL for shortening samples. Fat content affected the density of shortening icings (R^2 = 0.6). Color (L^∗) of shortening icings was not affected by the fat content (R^2 = 0.07).

It was found that density, water activity, and color are good indicators of physical quality of the shortening.

The freeze-dried SLC when mixed with liquid SLC readily dispersed and formed smooth icing when sugar was added. Reduced-fat icings made from SLC instead of shortening had fat content in the range of 1.2% and 12.8% fat. Water activity of SLC icings (constant solid content series) was 0.85. It had a positive correlation with fat content. This was thought to be due to varied starch and sugar to water ratio, as the fat was reduced the starchy increased but the water remained constant. It was confirmed by the low correlation (R^2 = 0.04) between fat and water activity for icings where sugar to starch to water ratio was kept constant. Overall fat did not affect the water activity of SLC icings.

Color of SLC (constant sugar to starch to ratio) icings was affected by fat content in the range of 1.2% and 12.8% fat. The lightness (L^∗) was reduced with decrease in the fat content of the icings in this series. This effect was due to sugar content (R^2 = 0.59), which increased from 70% to 77%. The lightness of SLC icings with constant solid content series was less affected by fat (R^2 = 0.27) and sugar (R^2 = 0.39). Thus, this confirms that the changes in color observed were due not to the reduction in fat content. Similar trends were seen for yellowness and redness part of the color for the SLC and shortening icings. The density of both series of SLC icings (1.2 to 1.4 g/mL) was higher than that of the shortening icings (1.0 to 1.3 g/mL). Fat content had a similar effect on SLC icings (R^2 = 0.72) as on the shortening icings (R^2 = 0.59).

Due to the lack of the literature available on icings, this study was an effort to understand the properties of shortening and SLC icings. Reduced-fat icings made from SLC had similar physical characteristics as those made from shortening, which indicates the viability of using SLC in icings. Further work is needed to study the effects of other ingredients on the characteristics of SLC icings and their optimization.

Rheology
The linear viscoelastic properties of the samples are compared in Figure 1, which shows the storage modulus at a frequency of 1 rad/s. Although there were some differences in the frequency dependence of the linear viscoelastic properties between samples, similar trends were observed for all of the samples. The storage modulus typically increased by a factor of 4 between frequencies of 0.1 and 100 rad/s, and the storage modulus was about 2 times higher than the loss modulus throughout this range. The storage modulus for the full-fat control was about 1.5 × 10^4 Pa. This value was maintained in the reduced-fat 100% shortening sample at a fat content of 16.75%, but further reduction in the shortening led to significant decreases in the storage modulus. All of the samples prepared with SLC had storage modulus values within a factor of 2 of the control down to fat contents of 10%, and in 1 case as low as 4.7% fat. For the constant solid content series of samples, the storage modulus tended to increase as the shortening was replaced.
Amylose shortening composite as cake icing...

with starch, and for the lowest fat levels, the storage modulus was about 5 times higher than for the control. This increase in gel strength could be due to interactions between swollen starch granules in SLC. A much more dramatic decrease was observed for the constant starch to sugar to water ratio series. The storage modulus decreased rapidly below 10% fat, and for the lowest fat samples it was only about 1% of the value of the control sample. The yield stress also remained almost constant down to a fat content of 10%, but the constant-solid series showed a much greater increase at lower fat levels (Figure 2). The yield stress increased by up to 6 times that of the control, whereas the yield stress did not drop by more than half for the constant starch to sugar to water ratio series.

The melting profiles for a range of samples are shown in Figure 3. Below 40 °C, all of the samples had a similar, weak temperature dependence. At higher temperatures, the melting behavior depended on both the fat level and the starch content. The storage modulus of the full-fat control (22%) decreased by almost a factor of 400 between 40 °C and 60 °C, whereas reduced fat (11%) decreased by less than a factor of 3. Most samples showed intermediate amounts of melting, as shown by the 13% fat and 9% fat SLC icings. Although their initial storage moduli were different due to their formulation, the storage modulus of each decreased by about a factor of 10 between 40 °C and 60 °C, with most of the decrease occurring below 50 °C. The ratio \( \tan \delta = G''/G' \) was also affected by the presence of the SLC. The control sample had a greater relative decrease in \( G' \) than for the samples prepared with SLC, similar to the results of Laneuville and others, 2005 for their low-fat frostings prepared with WPXC. \( \tan \delta \) became equal to 1 at 45.8 °C for the control, and increased slightly at higher temperatures. The maximum values of \( \tan \delta \) for the 13% and 9% fat SLC icings were 0.73 at 45.5 °C and 0.65 at 44.0 °C, respectively, whereas \( \tan \delta \) remained nearly constant at 0.37 ± 0.03 for reduced-fat SLC icing. In contrast to the results of Laneuville and others, 2005, no increase in the linear viscoelastic properties was observed above 50 °C. The melting profiles relate to the fate of icings in the mouth when consumed, and stability at storage temperatures. As expected, the results indicate that low-fat SLC icings do not melt as the shortening icings in the mouth. Rather icings would maintain their form and shape at higher temperature.

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Figure 1–Effect of fat and SLC on storage modulus of shortening and SLC icings. The constant solid SLC series is shown by solid symbols and the constant starch to sugar to water ratio SLC series is shown by open symbols.

Figure 2–Effect of fat and SLC on yield stress of shortening and SLC icings. The constant solid SLC series is shown by solid symbols and the constant starch to sugar to water ratio SLC series is shown by open symbols.

Figure 3–Melting characteristics of SLC and shortening icings. The solid circle represents the full-fat control icing made with shortening, sugar and water (sample #1); the open triangle represents the SLC icing made with liquid SLC having 24% fat and constant solid content series (sample #21); the open square represents the SLC icing made with liquid SLC having 24% fat and constant sugar to starch to water ratio (sample #23); the solid diamond represents SLC icing made with 16% fat liquid SLC having constant sugar to starch to water ratio (sample #14).
Texture

Consistency is an important property of icings, which has great effect on its eating quality and acceptability. Consistency is the force required to spread the frosting, indicating it to be smooth, thick, or gummy. Consistency of shortening and SLC icing as affected by the level of fat content is presented in Figure 4. The 2 SLC formulation series required considerably different forces to spread the icings. The constant solid SLC icings had thicker consistency, and this increased at lower than 10% fat levels. This could be due to less water available for the starch. SLC icings made using the constant starch to sugar to water ratio had considerably lower consistency values in comparison to the other SLC series, thus confirming that starch to water ratio affects the consistency of low-fat SLC icings. Statistical analysis also confirmed that constant solid content SLC series had significantly higher consistency values, while shortening and constant starch to sugar to water ratio had lower consistency values and did not significantly differ amongst each other. Fat level above 8% in liquid SLC did not significantly affect the consistency of icings in comparison to shortening icings. The amount of fat in freeze-dried SLC did not significantly affect the consistency of icings. Reduced-fat (10%) SLC icings had comparable consistency to the full-fat (22%) shortening icing. Further reducing the fat below 5%, the constant solid content SLC icings required more force and time to spread while the icings with constant starch/sugar/water ratio required lower force and time than the full-fat shortening icing. This indicates that besides fat, the ratio of water to starch and/or sugar solids also plays a role in the consistency of the samples. Lower water can result in consistency requiring more force and time to spread, resulting in a thicker layer of icing and/or tearing the baked product to which the icing is applied. Lower consistency depicts a runny icing forming a thin layer, not enough to cover the baked good.

By optimizing the starch to sugar to water ratio based on the data from the 2 series in this study, low-fat SLC can be prepared with consistency similar to full-fat shortening icings.

Crust hardness at day 0 for shortening and SLC icings is presented in Figure 5. Crust hardness is the force required for the initial bite representing the hardness of the frostings. Constant solid content SLC series had significantly higher crust hardness values, while shortening and constant starch to sugar to water ratio had lower hardness values and did not significantly differ amongst each other. Fat level above 8% in liquid SLC did not significantly affect the hardness of icings in comparison to shortening icings. The amount of fat in freeze-dried SLC did not significantly affect the hardness of icings. Reduced-fat (<10%) SLC icings having a constant sugar/starch/water ratio required similar force to penetrate the crust as full-fat shortening icings. A further reduction of fat in SLC icings required lower force indicating softer icings. SLC icings having constant solid content were harder as they required higher force to penetrate the crust. This confirms that the ratio of sugar and starch to water is an important factor contributing to the quality of the SLC icings, and low-fat SLC can be prepared with properties similar to full-fat shortening icings by optimizing the starch/sugar/water ratio based on the data from the 2 series in this study.

The maximum force required for extrude icings through a 3 mm hole, indicating the ease of piping out the icing during cake decoration, as affected by fat content and source of fat is presented in Figure 6. Liquid and freeze-dried SLC made with 24% fat did not significantly affect the extrudability of icings when compared to shortening icings. Reducing the fat to 5% in shortening icings required more force to extrude them. SLC icings followed a similar trend of increased force required with a decrease in fat content. A further decrease in fat (< 5%) resulted in lower extrusion forces similar to full-fat shortening icings. This higher extrusion force at low-fat levels for 8% fat SLC icing (4.7% fat) could be due to higher percentage of water (17%) and compared to low-fat SLC icings (16%) requiring lower extrusion force. Low-fat SLC icings can be prepared by optimizing the formulation at the required fat level.

Storage

All samples lost moisture during storage. At 2 days of storage shortening icing (22% fat) and SLC icings (5% to 13% fat) lost up...
to 10% moisture. Fat content (5% to 13%) did not seem to affect the moisture loss of SLC icings at 1 and 2, 6, 8, and 10 d of storage as they followed the same trend of increasing moisture loss with storage. Full-fat shortening icings also had an increasing moisture loss with time but to a lesser extent, this was expected as full-fat control icings had lower initial moisture content.

Conclusions

Water activity, color, refractive index, force of extrusion, consistency, crust hardness, and rheology are important characteristics for determining the quality of icings. Physical characteristics, rheology, texture, and storage studies indicate that starch-shortening composites can be used to substitute for shortening in the preparation of low-fat cake icings. It was found that 16% and 24% fat SLC can be used to prepare low-fat icings having as low as 6% fat. The sugar to starch to water ratio in the SLC icings plays an important role and needs to be optimized.

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References


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