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FUNCTIONAL BENEFITS OF MODIFYING MILKFAT PROPERTIES BY MICROENCAPSULATION

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ABSTRACT

Spray-dried milkfat powders were prepared from stable emulsions containing 40-60% milkfat (either butteroil or cream) and carbohydrate matrices (sucrose, modified starch or all purpose flour) according to a completely randomized factorial design.

Structural features of the powders examined by optical and scanning electron microscopy, showed powder particles that were spherical in shape with sizes ranging from 20 - 120 μm . Surface features of particles were encapsulant dependent. Melting patterns evaluated with a differential scanning calorimeter (DSC) showed well-defined melting ranges (20 - 230 deg C) that were related to encapsulant used. Moisture sorption isotherms of powders showed characteristic breaks caused by sugar crystallization followed by slight moisture desorption whereas powders with modified starch or all-purpose flour continuously absorbed moisture until the system equilibrated. Powders with 50% milkfat from cream encapsulated in all-purpose flour were successfully substituted for liquid corn oil in a muffin formulation.

1. INTRODUCTION

Reduced fat consumption due to changing dietary habits has resulted in a world-wide surplus of butter. This trend is expected to continue in the near future, which will create severe storage problems (USDA, 1991). Though salted butter can be readily stored frozen for up to three years, freezer space is limited and costly. A storage life of 12 to 24 months at ambient temperatures can be achieved if the milkfat is converted to a powder (Claypool, 1984). Research has demonstrated that production of high fat butter powders is technically possible, but wide-spread use has not followed, due to processing difficulties (Hansen, 1963; Patel, et al., 1987). The alternative is spray drying of milkfat with functional encapsulants such as starch, proteins or gums that would enhance stability of the powder. Stability is attained through the formation of microregions that protect the milkfat from oxidative deterioration during storage. We have demonstrated that anhydrous butteroil or cream may be successfully encapsulated in carbohydrate matrices although the physical and structural properties varied with the source of milkfat and the type of encapsulant used (Onwulata et al., 1993).

Milkfat is considered to be a quality-enhancing ingredient in foods, with the melting characteristics being very significant. Proper and timely melting of milkfat is necessary in developing flavor and enhancing texture. The melting pattern of milkfat has been well-studied in the range of -10 to 40 deg C. It is known that milkfat oxidizes and decomposes during prolonged heating at high temperatures (Chang et al., 1978). Encapsulation modifies the melting range of butter oil and reduce the rate and extent of decomposition.

Thermal analysis has been used to monitor changes in chemical properties of starches as a function of temperature, by detecting changes in heat capacity associated with the gelatinization and retrogradation process. Processing alters the physical state of disaccharides, enhancing transitions to an amorphous or crystalline form (Kim and Walter, 1992; Niediek, 1988). An amorphous glass entraps flavor compounds and protects encapsulated materials from oxidation due to slow diffusion of, for example, encapsulated oil

from the interior to the surface of the capsule and of oxygen to the interior; however, encapsulant crystallization results in higher diffusion rates or causes complete release of encapsulated compounds through capsule rupture (Roos and Karel, 1991). In the crystalline state, sugars imbibe little water at low relative humidity. At high water activity ($a_w = 0.8-0.85$), sugars such as sucrose begin to dissolve. Amorphous sugars absorb substantial amounts of water at low relative humidity, leading to crystallization and abrupt moisture desorption. An excellent example of such behavior is that of the milk sugar, lactose, in milk or whey powder which, if present in the amorphous state, absorbs water and crystallizes to form the alpha monohydrate, resulting in caking (Mistry et al., 1992).

The choice of encapsulant is critical as the material will influence emulsion stability before drying, and flowability, mechanical stability and shelf life after drying. For the production of butter powders, the solids-not-fat matrix may consist of milk protein products such as nonfat dry milk, sodium caseinate or whey proteins, various sugars, and gums.

2. OBJECTIVES

Examine the internal structure and surface morphology of encapsulated powders containing 40-60% milkfat. Investigate the physical characteristics and thermal behavior and verify the effect of water imbibition on the structural integrity of the spray dried microcapsules when exposed to high humidity at ambient temperatures. Test functionality in preliminary baking trials.

3. MATERIALS

Anhydrous butteroil was purchased from a commercial distributor (Land o' Lakes, Minneapolis, MN) and heavy cream from a local dairy (Longacre's Modern Dairy, Inc., Barto, PA). Encapsulants selected were sucrose (Domino's, Domino Sugar Corp, New York, NY), modified starch (M-starch) (Capsul™, National Starch and Chemical Co., Bridgewater, NJ) and all-purpose flour (N-starch) (ADM Milling Co., Kansas City, MO). An emulsifying agent (mono- and di-glycerides) (American Ingredients Co., Kansas City, MO) was also used. The protein source was nonfat dry milk (Maryland and Virginia Milk Producers Association, Inc., Laurel, MD). Encapsulated powders were formulated to have 40, 50 or 60% milkfat, 5% emulsifier and 5% nonfat dry milk. Sample preparation was as follows: The encapsulant was dry-blended with nonfat dry milk solids, dispersed in water, then mixed with a warmed (24 deg C) emulsion of anhydrous butteroil or cream and emulsifier, and heated at 24 deg C for 5 min with stirring. The constantly stirred slurry (40% total solids) was slowly brought to the final temperature (63 deg C), and homogenized at 17.2 MPa with a Manton-Gaulin Model 100 DJF3 855X Triplex homogenizer (APV Gaulin, Inc., Everett, MA). The homogenized emulsion was spray dried in a compact dryer (APV Crepaco Inc., Attleboro Falls, MA). Spray dryer inlet temperature was 180-190 deg C, and an outlet temperature of 80-110 deg C was maintained. The powders were produced in batches, removed from the dryer after 30 min and stored at 4 deg C until used.

4. METHODS

4.1 MICROSCOPY

Structural features of all samples were examined by optical and scanning electron microscopy.

4.1.1 Optical Microscopy

Samples of powders were sprinkled on cm-long segments of Double Stick Tape (3M Company, St. Paul, MN) on microscope slides. Excess powder was removed from the surface of the tape using a jet of pressurized air. A drop of immersion oil was added to the layer of adherent powder particles, and a coverslip was applied. Optical magnifications were calibrated using a slide micrometer with an Olympus BH2 phase contrast optical microscope (Olympus Corp., Lake Success, NY).

4.1.2 Scanning electron microscopy

Samples of powders were sprinkled on aluminum specimen stubs coated with Spot-o-Glue labels (Avery, Azusa, CA). Specimen stubs were coated with a thin layer of gold in a DC cold sputtering module in an E306A vacuum evaporator (Edwards High Vacuum, Inc., Grand Island, NY). Observations and images were made in the secondary electron imaging mode of a JEOL Model 840A electron microscope (JEOL, USA, Peabody, MA).

4.2 DSC ANALYSIS

A Perkin-Elmer differential scanning calorimeter, Model DSC-7, equipped with an Intracooler II refrigeration unit was used to measure thermal characteristics (Perkin Elmer Corp., Norwalk, CT). Ten mg +/- 1 mg of sample were weighed into aluminum pans (Perkin-Elmer) and hermetically sealed. An empty sample pan was used as a reference. Heating was from -25 to 350 deg C at 20 deg C/min after initial cooling to -30 at 20 deg C/min. The heat of melting, in joules per gram of sample, was determined by dividing area under the curve by sample weight.

4.3 MOISTURE SORPTION ISOTHERMS

Moisture sorption isotherms were obtained at 25 deg C by equilibrating 10-g powder samples with known water vapor pressures provided by the following saturated salt solutions: CaSO₄, LiBr, LiCl, K₂CO₃, MgCl₂, K₂CO₃, Mg(NO₃)₂, KI, and (NH₄)₂SO₄ (Rockland and Nishi, 1980) for 72 hr. Moisture uptake by encapsulated powders was determined after equilibrating for 200 hr over anhydrous K₂CO₃. The weight change was determined after drying under vacuum for 4 hr at 102 deg C (AOAC, 1984).

4.4 BAKING STUDIES

Encapsulated milkfat (50% fat from heavy cream encapsulated in all-purpose flour)(N-starch) was substituted weight-for-weight for corn oil and flour in a standard cranberry-orange muffin formulation. (The control formulation contained 24.6% all-purpose flour, 24.3% sucrose, 0.6% double acting baking powder, 0.3% salt, 12.8% beaten whole fresh egg, 0.1% dehydrated orange peel, 13.3% reconstituted frozen orange juice, 5.3% corn oil, and 18.7% sliced fresh cranberries). Dry ingredients were weighed and dry-blended in a Kitchen Aid™ 4-qt mixing bowl, then blended for 1 min with the previously mixed wet ingredients. If cranberries were added to the formulation, fresh cranberries were washed, drained and sliced in a Cuisinart™ Food Processor before being weighed and folded into the batter. Dehydrated cranberries, prepared by explosion puffing (Sullivan and Craig, 1984), were rehydrated for 1 hr in cold water, drained and substituted weight-for-weight for sliced fresh cranberries in the formulation. The overall control had no added cranberries and contained corn oil as the shortening. Batter was evenly divided into 6.9 cm muffin tins (57 g/muffin) previously sprayed with a flour-oil mixture and baked at 205 deg C for 20 min in a Despatch Rotary Oven Model 150 (Despatch Industries, Inc., Minneapolis, MN), equipped with a single revolving shelf. Muffins were cooled on wire racks to ambient temperature, packed in freezer bags and stored frozen in a single layer until needed.

4.5 MECHANICAL TESTING

Texture profile analysis (TPA) was performed with hardness, springiness and cohesiveness being determined at 25 deg C with an Instron Universal Testing Machine Model 4201 (Instron, Inc., Canton, MA), equipped with a 500 N compression load cell. The Instron Cyclic Foam Compression Test Software was used for data acquisition and control during the test. The muffins were compressed to 60% at a crosshead speed of 10 cm/min. Force versus time curves were analyzed into hardness, springiness and cohesiveness values according to the methods and definitions used by Bourne (1978).

Muffins for TPA analysis were returned to the muffin tin while frozen and the top sliced off even with the top of the pan. A plug, 30 mm high by 48 mm in diameter, was cut from the center of the frozen muffin with a 48 mm diameter metal cylinder. Samples were covered tightly with plastic wrap, equilibrated to ambient temperature for 2 hr and analyzed.

5. RESULTS AND DISCUSSION

5.1 MOISTURE CONTENT

Moisture content of the spray dried powders varied from 1 - 4%, with highest moisture (3.76%) in the sample prepared with unmodified starch and anhydrous butteroil (Onwulata et al., 1993). The amount of fat and the type of encapsulant in the emulsion significantly affected powder moisture content. Moisture content is critical in dehydrated products, because it has long been known that a small residue of water appears to be a major factor in inhibiting fat oxidation (Koch, 1962). Fat retention (determined by measuring the amount of fat extracted after exposure to solvent for a specified time) within the microcapsule varied from a low of 45% in un-modified starch to a high of 95% in sucrose powders. Retention efficiency declined in all cases as the fat content increased from 40 to 60% (Onwulata et al., 1993).

5.2 MICROSCOPY

Optical images of powders made from anhydrous butteroil or heavy cream to contain 40% fat, with M-starch, sucrose, or N-starch as the encapsulating agent were examined. They reveal differences in structural features of the constituent particles related to the type of carbohydrate matrix formed by spray drying, but not to the source of milkfat (Fig. 1). M-starch particles with butteroil or cream were roughly spherical in shape, and contained one or more internal cavities of low refractive index (Figs. 1A and 1D, respectively). The cavities ranged in diameter from around 5 to 20 micrometers. The powder particles with sucrose as the encapsulant were smooth spheres, containing optically bright, homogeneous granular material (Figs. 1B and 1E, butteroil or cream, respectively). Powder particles containing N-starch as the encapsulant were large, roughly spherical, and contained an admixture of coarse granular material, which often included several whole starch granules (Figs. 1C and 1F, butteroil or cream, respectively). In each case, particles with each type of encapsulant, containing 40% milkfat as butteroil or cream, were comparable in size and structure, indicating that stable powders could be made from both sources of milkfat.

M-starch functions as a good encapsulant for fats (King et al., 1976); however, in our study, there was a great tendency to occlude air which may be detrimental to long term storage when milkfat is encapsulated. Occluded air and vacuoles may arise from air incorporation into the emulsified concentrate before spray drying (Caric and Kalab, 1987). Powders with sucrose as the encapsulant tended to agglomerate; the amount was dependent on the "stick-point" temperature and moisture content, which are functions of the drying process (Downton, et al., 1982). Powders made with N-starch as the encapsulant were lumpy at high fat levels, probably because of significant amounts of extractable fat (Onwulata et al.,

1993), some of which was on the particle surface. Surface fat acted as a binder for the particles, causing them to clump together.

5.2.1 Optical Phase Contrast Micrographs

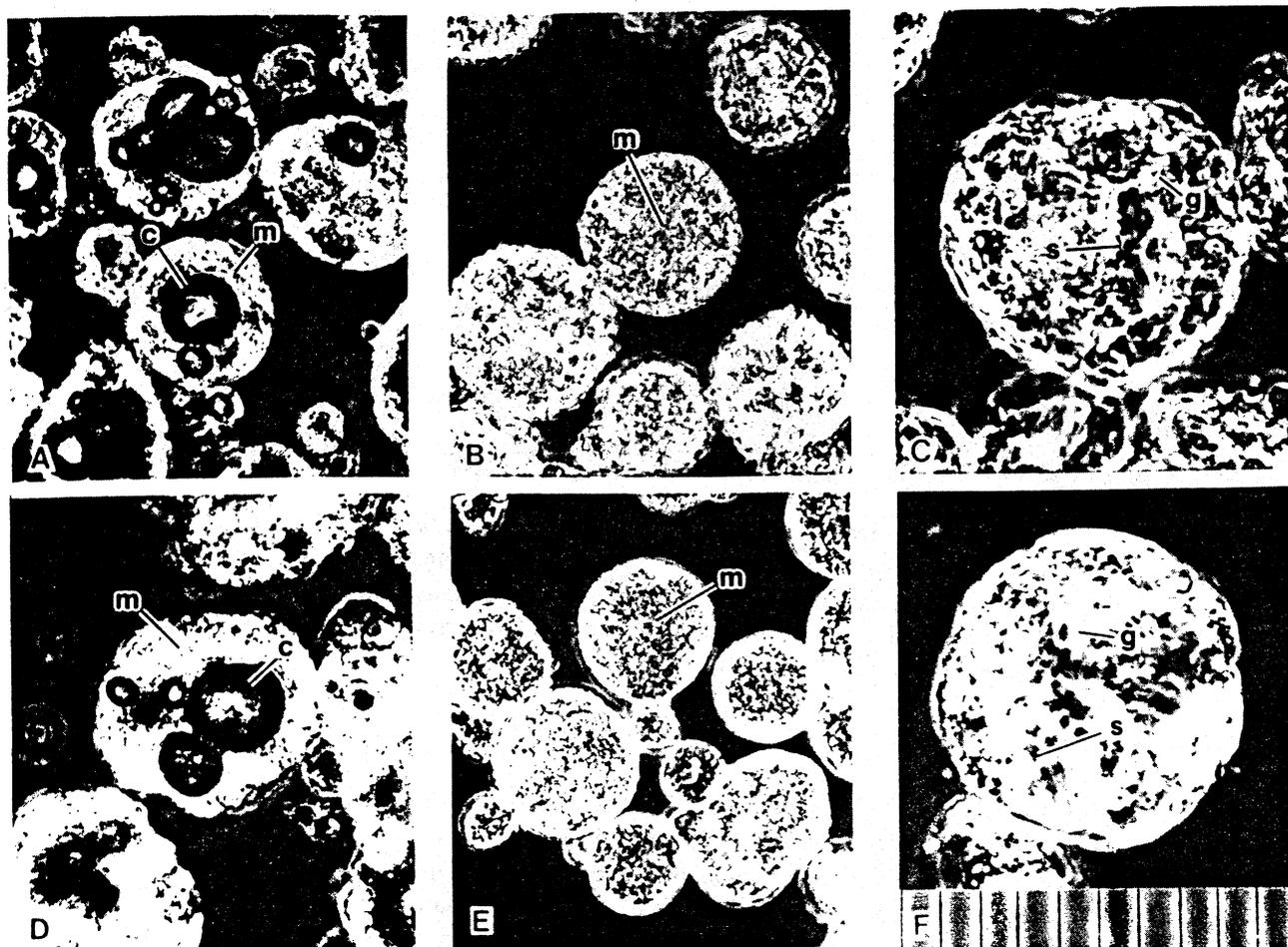


Figure 1. Optical phase contrast micrographs of powders prepared with three different carbohydrate encapsulating agents and containing 40% anhydrous butteroil (A,B,C) or cream (D,E,F) as the fat source. A. M-starch showing hollow cavities, (c), and surrounding matrix (m). B. Sucrose showing uniform matrix (m). C. N-starch showing coarse granules (g) and portions of whole starch granules (s). D. M-starch cream showing cavities (c) and matrix (m). E. Sucrose in a homogeneous matrix (m). F. N-starch showing comparable coarse granules (g) and starch (s), and slide micrometer with line spacings of 10 micrometers.

Dry-fractured particles of each type of powder made with 40% anhydrous butteroil were examined to resolve internal structures (Fig. 2). All fractured particles with M-starch as the encapsulant contained a large empty vacuole surrounded by a thick somewhat porous wall. The wall contained a few large and many small vesicles, giving this structure the appearance of a foam (Fig. 2A). Evidently, the milkfat droplets are entrapped in the wall matrix in such a manner that they are not readily extractable when the milkfat content is only 40%. Fractured powder particles with sucrose as the encapsulating agent had no large central cavities but contained a uniform distribution of vesicles with a narrow size range, around 200-300 nm in diameter, embedded in a solid matrix (Fig. 2B). Milkfat is apparently encapsulated in small pockets within the matrix; small droplets are located around the edges of the particle and small holes, possibly containing fat, are scattered throughout the particle. Projections on the surface of these particles appeared to be smaller particles stuck to the "sticky" surfaces of the hot powder during the drying

process. Fractured powder particles with N-starch as the encapsulant contained a hollow central cavity lined with the surfaces of large smooth granules and surrounded by a thick porous wall (Fig. 2C). These powder particles had a loose matrix of carbohydrate and protein surrounding large fat globules.

5.2.2 SEM of Dry Fractured Particles

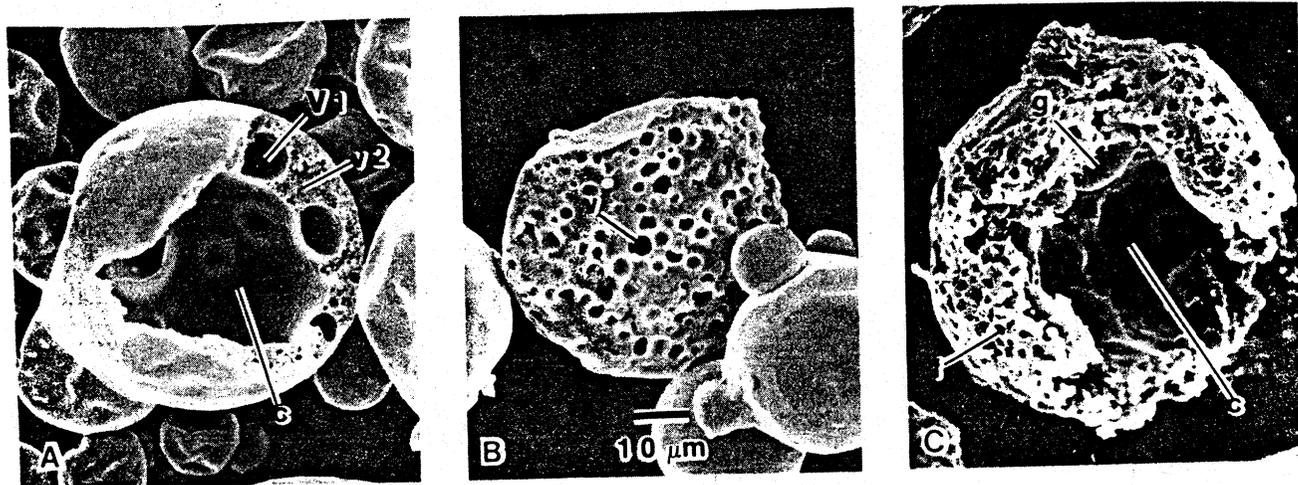


Figure 2. Scanning electron micrographs of dry fractured particles with 40 % butteroil. A. M-starch particle showing central cavity (c) and a few large (V1) and many very small (v2) vesicles in the matrix wall, B. Sucrose particle with a uniform distribution of small vesicles (v) and a 10 micrometer line, and C. N-starch particle showing cavity (c), portion of granule (g) and fenestrations in the matrix wall (f).

5.3 THERMAL PROPERTIES

To identify shifts and complex patterns in the thermograms of the encapsulated powders, it was first necessary to identify the melting peaks of the various components used in product preparation. Table 1 lists the transition points for the components used for the encapsulation of the milkfat. The melting pattern for butteroil found in the DSC thermogram showed many peaks from -40 to 40 deg C. When heated above this region, butteroil gradually decomposed, but without the appearance of additional peaks in the thermogram. Taylor et al. (1978) has reported thermal decomposition of butteroil beyond this melting region. The emulsifier melting range was from 37 to 165 deg C with peaks at 46 and 150 deg C. Melting peaks for M-starch were around 99 deg C, N-starch at 118 deg C and sucrose at 190 deg C.

5.3.1 Melting Properties of Materials

TABLE 1. MELTING PROPERTIES OF MATERIALS USED FOR ENCAPSULATION

Product	Peak (°C)	Melting Range (°C)	ΔH (J/g)
Butteroil	*	-40 - 40	**
Sucrose	190	180 - 196	122.2
M-Starch	99	60 - 150	85.4
N-Starch	118	60 - 201	250.4
Emulsifier	46	37 - 165**	27.6

* Numerous Peaks within the melting range.

** More than one peak.

M-starch = modified starch; N-starch = all-purpose flour; Emulsifier = mono- and di-glycerides.

DSC thermograms of the spray-dried powders with 40 or 60% anhydrous butteroil encapsulated in three different carbohydrate matrices are shown in Figs. 3A-F; the heat of melting and peak temperatures are listed in Table 2. As shown by the thermal profiles, two major melting zones are present for each product containing 40 or 60% encapsulated fat, indicating the melting of the surface or unencapsulated fat and fusion of the wall material. Thermograms of butteroil encapsulated within the N-starch matrix (Figs. 3A and 3B) showed melting of the butteroil from 0 to 40 deg C; peaks in the thermograms of powders with 60% milkfat showed better definition and the heat of melting was much greater, indicating the presence of more butteroil. Thermograms for the M-starch/butteroil capsules show one main peak and a curve from 53 to 175 deg C (Figs. 3C and 3D), with heat of melting again varying with the amount of fat encapsulated in the powder. Capsules with sucrose as the encapsulating agent (Figs. 3E and 3F) had three fusion zones: surface fat peaks, 17 to 38 deg C, sucrose peaks, 178 to 184C, and high temperature peaks above 220 deg C. The capsules with 40% fat encapsulated in sucrose showed a disassociation product peak at 239C (Fig. 3E and Table 2) whereas the sample with 60% fat disassociated at a maximum of 236C (Table 2). The thermal patterns are those of true capsules with defined event times for the fusion of the various components comprising the powders.

Thermal properties of milkfat polymorphs and their crystallization properties have been studied in detail (van Beresteyn and Schaap, 1971; Patel and Frede, 1991). The triglyceride structure and fatty acid composition served as the basis for determination of solid fat indices and melting patterns. We did not try to identify the crystalline forms of the anhydrous milkfat in our powders. As shown in Table 2, melting peaks for the six powders studied all fell within the known melting range for milkfat.

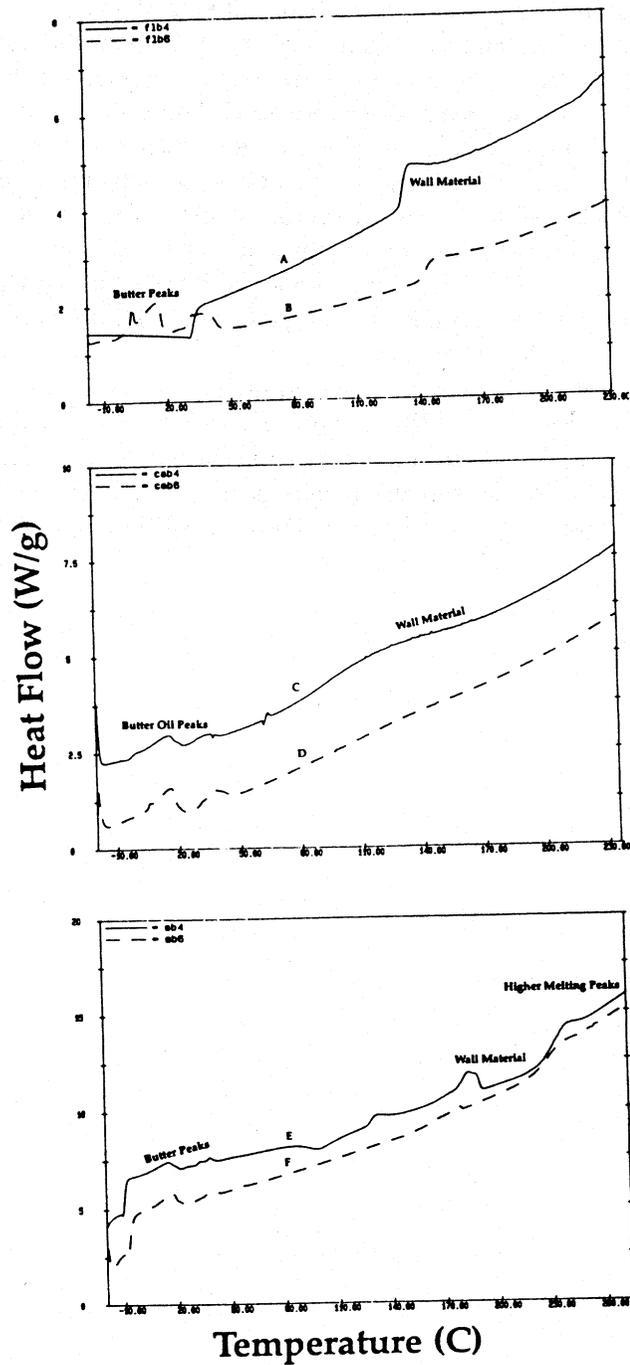


Figure 3.

DSC thermograms of encapsulated butteroil powders. 1A and 1B: All-purpose flour (N-starch) and 40% and 60% butter oil. 40% powder shows minimal butter oil peak and a starch degradation peaks. 60% fat-containing powder shows a pronounced butter oil peak and a smaller degradation area for starch. 1C & 1D: Modified starch (M-starch powders with 40 and 60% fat content, showing butter oil peaks and gradual melting of the capsule wall material. 1E and 1F: Sucrose and butteroil powders with 40 and 60% fat content, showing the melting zones for butter oil, sucrose and by-product.

TABLE 2. MELTING CHARACTERISTICS OF MILKFAT ENCAPSULATED IN CARBOHYDRATE MATRICES

Product	Surface Fat		Encapsulant Load					
	Peak	ΔH	Peak	ΔH	Peak	ΔH	Peak	ΔH
	-----	ΔH	J/g	-----	Peak	$^{\circ}C$	-----	-----
N-Starch40	*	*	36.0	10.6	134.4	27.6		
SD			0.0	2.1	2.6	0.4		
N-Starch60	4.0	25.2	39.1	13.6	148.5	19.6		
SD	0.0	0.0	0.1	0.5	0.5	4.3		
M-Starch40	15.2	15.3	34.1	2.5	112.8	58.4		
SD	0.2	0.2	0.1	0.8	0.2	4.1		
M-Starch60	15.8	24.9	36.1	8.3	96.7	9.6	-----	-----
SD	0.2	4.0	2.1	0.0	0.3	0.8		
Sucrose40	17.6	14.5	38.0	4.9	183.8	42.5	239.1	23.9
SD	0.6	0.0	0.0	0.1	0.2	0.0	0.1	1.7
Sucrose60	16.8	24.3	36.2	3.6	177.8	4.7	235.8	15.0
SD	0.2	2.0	0.2	0.1	0.2	2.4	0.2	1.9

*: Insignificant melting peaks.
 --: No thermal products after carbohydrate peak.
 N-starch = All-purpose flour and butter oil.
 M-starch = Modified starch and butter oil.
 40 and 60 = 40% and 60% milkfat.
 SD = Standard Deviation

It has been reported that complexes formed in the presence of saccharides change the melting patterns of the components. Krog et al. (1989) described a disassociation of amylose-lipid complex at 100-120 deg C, with the heat of disassociation increasing in the presence of monoglycerides. Lipid-saccharose complexes appeared as high melting peaks. Starch degradation studies have shown that in the presence of sugar and emulsifiers, peak temperatures are increased (Buck and Walker, 1988; Donovan, 1977). Here, the M-starch (modified starch) showed a peak temperature increase of 13 deg C with a 40% fat content whereas, with 60% fat, there was little change (2 deg C) in peak temperature (Tables 1 and 2). In contrast, the N-starch (all-purpose flour) showed peak temperature increases of 16 and 30 deg C for powders with 40 and 60% fat, respectively (Tables 1 and 2), suggesting that greater changes are occurring in the starch moiety of this encapsulant as a result of the association with fat. When sucrose was used as the encapsulant, maximum peak temperature decreased, with the greatest decrease (13 deg C) observed in the powder with 60% fat (Tables 1 and 2). The capsule must rupture at the appropriate time if encapsulated milkfat is to be used as a shortening in such products as dry bakery mixes. This permits the shortening to be delivered at the appropriate time; our results suggest that it might be possible to tailor capsule rupture temperature to the baking process by careful choice of encapsulant and encapsulating process.

Sorption isotherms of powders encapsulated in sucrose, N-starch and M-starch, with 40 or 60% butteroil are presented in Fig. 4. Sucrose/buteroil powders showed characteristic sorption patterns across the range of water activities examined. A similar break in the sorption isotherm between 40-50% relative humidity was reported for spray-dried milk powders, attributed to the crystallization of α -lactose monohydrate (Berlin et al., 1969; Pisecky 1992). The sorption isotherm for crystalline sucrose differed from those of amorphous sucrose (Niediek, 1988; Moreyra and Peleg, 1981). Even though a small amount of lactose was present (about 1/20 of the total disaccharide present), we attributed the characteristic breaks in the isotherms of the sucrose/butter oil powders to crystallization of amorphous sucrose. It is very possible that powders encapsulated with sucrose would crystallize eventually, even in low humidity, suggesting that these powders must be protected from moisture uptake during storage by low-water-vapor-permeable packaging. M-starch/butter oil and N-starch/butter oil isotherms showed patterns typical of water absorption for flours or gums, with steady increases in moisture sorption with increasing humidity. Oxidative stability may be expected for the sucrose/butter oil powders between 0.1-0.2 a_w and for M-starch/butter oil and N-starch/butter oil powders between 0.2 - 0.4 a_w , based on the moisture monolayers (Karel, 1975).

5.4.1. Moisture Sorption Isotherms of Powders

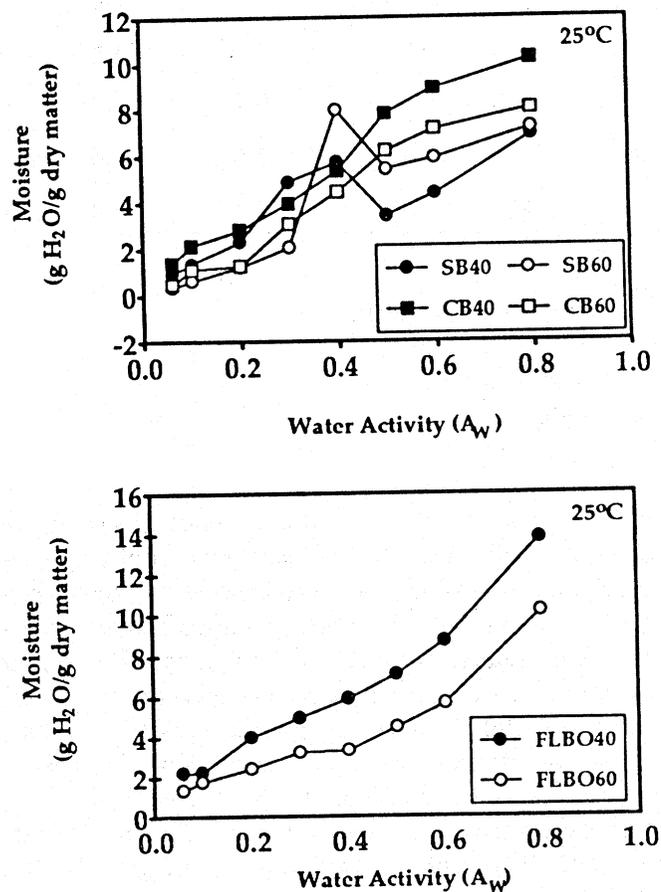


Figure 4. Moisture sorption isotherms of powders with 40 or 60% butter oil and sucrose, modified starch (M-starch) or all-purpose flour (N-starch) as encapsulant. sb4 = sucrose 40; sb6 = sucrose 60; cab4 = M-starch 40; cabs = M-starch 60; flb4 = N-starch 40; flb6 = N-starch 60.

The results of TPA analysis are shown in Fig. 5. Relative hardness, cohesiveness and springiness are presented for six types of muffins. Muffins, prepared with milkfat encapsulated in the N-starch matrix (ES) without added cranberries, were softer, slightly more springy and less cohesive than the control (C). Increase in volume in both the batter and the baked muffin was noted when encapsulated shortening was substituted in the formulation, but no formal measurements were made. The addition of fresh cranberries decreased springiness and cohesiveness with the greatest decreases seen in the sample with encapsulated shortening (ESCB); hardness decreased only slightly. Substitution of rehydrated cranberries for fresh cranberries in the formulation produced muffins that were more springy and harder than muffins with fresh cranberries (CSCB, CSEB); the same trend was seen in muffins made with the experimental shortening (ESCB, ESEB). Muffin cohesiveness varied independently of the type of shortening or cranberry used in the formulation. Batter and muffin volume were apparently increased by the use of encapsulated milkfat, probably because the foam structure formed in the presence of milkfat emulsified with mono- and diglycerides was modified during mixing and baking. We speculate that the new foam was less cohesive, not as hard and more springy than that produced with the use of corn oil in the formulation. The role of emulsifiers and shortening in improving the texture of baked goods is well known (Van Haften, 1979; Hartnett, 1976). Our results suggest that encapsulated butter powders make excellent shortenings.

5.5.1 Texture Profile of Muffins

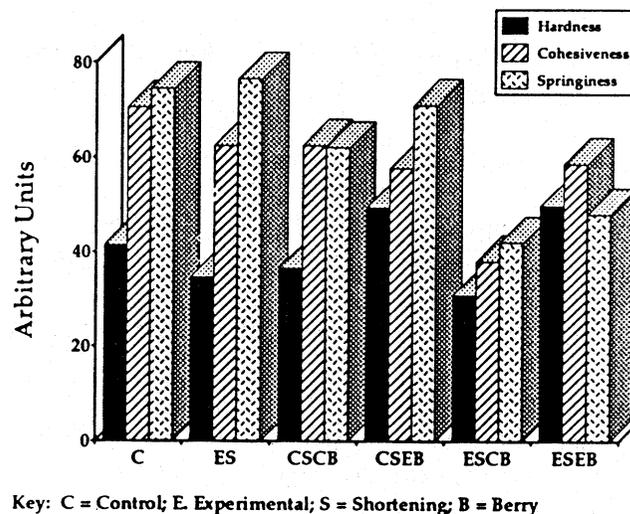


Figure 5. Texture profile of muffins made with encapsulated milkfat and dehydrated cranberries, compared to muffins prepared with corn oil and fresh cranberries. C = Control; E = Experimental; S = Shortening; B = Cranberry

6. CONCLUSIONS

The structures of milkfat containing powders encapsulated in carbohydrate matrices show distinct features. Powders with M-starch as the encapsulant entrapped milkfat in the wall matrix; however, powder particles contained large quantities of occluded air, suggesting reduced stability to oxidative deterioration. Powders with N-starch showed a loose matrix, without true capsule formation, enclosing large milkfat droplets; this structural weakness may permit easy air diffusion into the interior cavity, enhancing milkfat oxidation. Milkfat globules were successfully encapsulated when sucrose was used as the encapsulating agent; no occluded air or large vacuoles were present. With minimal solvent-extractable

fat, powders with sucrose were structurally stable, suggesting good resistance to oxidative deterioration. Spray dried encapsulated milkfat powder shows great potential for use as a food ingredient in such products as dry bakery mixes. Well-defined melting ranges are identifiable in DSC profiles; melting temperatures for capsule rupture and release of the fat load are associated with type of encapsulating agent chosen. Moisture uptake and sorption isotherms are also related to encapsulant and demonstrate the need for special packaging to prevent moisture imbibition during storage. Baking trials demonstrated the successful substitution of 50% milkfat from heavy cream encapsulated in N-starch for vegetable oil in a muffin formulation. Ease of moisture uptake can be advantageous in a batter when dry mixes are reconstituted for baking.

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