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Effect of Coencapsulating Milkfat and Leavening Agents on Batter Rheology

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ABSTRACT

Single- and double-acting baking powders were coencapsulated with butter oil and carbohydrate matrices forming instant baking mixes. Batters formulated from the encapsulated and coencapsulated powders were significantly more elastic ($P < 0.05$) than batters from the standard non-encapsulated formulation. The process of coencapsulating baking powders and butter oil in carbohydrate matrices resulted in a loss (25–75%) of the leavening power (CO_2). The loss of CO_2 potential in the batters resulted in lower weight loss in baked muffins.

Milkfat has been successfully encapsulated in different matrices such as carbohydrates, saccharides (1), and whey proteins (2). Butter oil encapsulated in flour matrices is a fitting adjunct to bakery mixes, where the milkfat would serve as a flavorful shortening. Butter oil encapsulated in all-purpose flour has been shown to have better proofing and rising in a muffin formulation than in a control formulation of the same composition (3). Butter powder also has been shown to have satisfactory baking performance (4).

Incorporating baking powders with butter oil and encapsulating them in all-purpose flour makes complex but useful instant bakery mixes. Chemical leavening agents can be blended into baking mixes. The blending action, however, can cause a breakdown of the delicately formed encapsulated matrix and increase the potential for oxidation and the development of rancidity. Our previous study with silica-based flow agents showed that degradation of capsule wall materials compromised the integrity of encapsulated sucrose powders (5).

Coencapsulation of baking powder with butter oil significantly reduces the potential damage to the wall matrix. Coating sodium bicarbonate ($NaHCO_3$) with fat prolongs the activity of $NaHCO_3$ and prevents premature release of CO_2 (6). The timing of CO_2 release greatly affects both the leavening and overall quality of the product (7). Our purpose in this study was to investigate the efficacy of coencapsulating $NaHCO_3$ directly in bakery mixes and to determine the batter functional characteristics and performance in baked muffins.

MATERIALS AND METHODS

Anhydrous butter oil was received from the USDA Agricultural Stabilization and Conservation Service (ASCS) (Washington, DC). Selected encapsulants were sucrose (Domino Sugar Corp., New York, NY) and all-purpose flour (ADM Milling Co., Kansas City, MO). The emulsifying agents used were mono- and di-glycerides (American Ingredients Co., Kansas City, MO) and the protein source was nonfat dry milk (Maryland and Virginia Milk Producers Association, Inc., Laurel, MD). Encapsulated powders were formulated to have 50% milkfat, 5% emulsifier, 5% nonfat dry milk (NDFM), and 40% sucrose or all-purpose flour.

Coencapsulated powders required modification of the standard preparation, which was published previously (1). Baking powder was dissolved in water and held below 20°C to minimize dissipation of the CO_2. The slurry was then combined with butter oil/emulsifier (50°C) and the wall material/NFDM (25°C) and brought to 60°C before homogenization at 17.2 MPa. The homogenized mixture was quickly cooled to 35°C and spray dried at an inlet temperature of 193–196°C and an outlet temperature of 82–88°C. The powders were produced in batches and stored at 4°C until used for baking.

Three formulations were evaluated as follows: 1) the standard formulation, made with nonencapsulated ingredients, was used as the control; 2) the blended formulation, where baking mixes were formulated with butter oil encapsulated either in flour or sucrose and the baking powder dry-blended into the encapsulated powder; and 3) the coencapsulated formulation, where either single-acting (SA) or double-acting (DA) baking powder was coencapsulated with the butter oil using either flour or sucrose as encapsulant. SA baking powder contained starch, sodium aluminum phosphate, and sodium bicarbonate. DA baking powder contained sodium acid pyrophosphate, sodium bicarbonate, starch, and monocalcium phosphate.

Dough Properties

The dynamic viscoelastic response to shear in the oscillation frequency (ω) range 0.01–100 rad/sec with fixed amplitude was investigated. A strain test was used to determine the range of linear viscoelasticity. The tests were performed at 25°C with a Rheometrics Dynamic Analyzer RDA-700 (Rheometrics Inc., Piscataway, NJ), using a 0–200 g·cm torque transducer equipped with a 2.0-cm-radius parallel plate with a height of 0.2 cm. Changes in viscoelastic properties as a function of frequency were determined through dynamic shear measurement that gives the shear storage modulus (G') and loss modulus (G''). Complex viscosity (η^*) was determined from a frequency sweep at 1.0 rad/sec. The relationship between dynamic moduli is as follows: $(G^*)^2 = (G')^2 + (G'')^2$ with $\eta^* = G^*/\omega$. The ratio of energy loss to energy saved is given by the loss tangent ($\tan \delta = G''/G'$) and represents the relative elasticity within a material showing network formation and breakdown (8).

Gas Analysis-Rising Potential

A gas production analyzer (National Cereal Chemistry Equipment, Lincoln, NE) was used to analyze differences in patterns of gas production. Ten grams of blended ingredients containing the baking powder were mixed with 7 ml of water in the sample container. The pressure meter was maintained at 30°C in a temperature controlled water bath. The diastatic pressure resulting from gas production was monitored for 100 min, per AACC Method 22-11 (9).

Baking Studies

The control contained vegetable shortening. Butter oil encapsulated or coencapsulated in all-purpose flour (F50), or sucrose (S50), was substituted weight-for-weight for shortening in various muffin formulations (Table I). Dry ingredients were weighed and dry-blended in a 4-qt mixing bowl, then blended for 1 min with the remaining ingredients, which had been previously mixed. The batter was placed in a pan that was previously sprayed with a flour-oil mixture and baked in a Despatch rotary oven model 150, equipped with a single revolving shelf (Despatch Industries, Inc., Minneapolis, MN). Baked products were cooled, packed in freezer bags, and stored frozen (–20°C) in a single layer until needed. Three replicates of each formulation were prepared. Moisture content of the products was determined by the AOAC method (10). Muffin height as an indicator of expansion was measured with a Vernier caliper (Monostat, Switzerland).

Color differences of the baked products were evaluated with a Gardner color meter equipped with illuminant A (model TCM infrared spectrophotometer) (BYK-Gardner, Inc., Silver Springs, MD). Measurements were made using the CIELAB color coordinates. Chroma was calculated as: $[(\Delta a^2) + (\Delta b^2)]^{1/2}$.

Product specific volume was determined by difference, by calculating the displaced volume of rapeseed. The baked product was placed in a 500-ml plastic container and the container filled with rapeseeds, leveled, and weighed. Specific volume was calculated by difference from eight samples taken for each of the three replicates.

Hardness of the muffins was determined using a texture analyzer model TA-TX2 (Stable Micro Systems, Surrey, UK) as the height of the first peak (kg). Muffin samples were cored and sliced into 11-mm-high × 21-mm-diameter cylinders and compressed at a crosshead speed of 12 mm/min to 30% of original height. All tests were conducted at room temperature.

RESULTS AND DISCUSSION

The effectiveness of different baking powders depends on the formulation and CO_2 release mechanism. The quantity of the CO_2 deliverable to the product depends on the type of baking powder and concentration (Fig. 1). CO_2 retention within the batter depends on temperature and the mechanism of release. The coencapsulation process, which involves dissolving the baking powder and then spray drying, leads to early release of the gases. This is particularly evident in the SA baking powder, where the loss of gassing potential (CO_2) was approximately 50% of that of the DA baking powder, where losses were 24–40%. Loss of gassing potential is evident when the three formulations are compared (Table II). Dry-blended and control formulations were not significantly different ($P < 0.05$) in the sucrose batter.

The DA baking powder, designed to remain active until high temperature baking, retained more CO_2 (11). DA baking powder is better from the standpoint of gassing potential after coencapsulation. Optimizing the DA powdered formulation for maximum retention in coencapsulation is more practical.

Viscoelastic properties of the formulated muffin batters are presented in Table II. Complex viscosity values show that the coencapsulated doughs were more structurally elastic than the blended. Generally, the complex viscosity was inversely related to gas production, suggesting that increased complex viscosity may be due to the retention of the CO_2 in coencapsulated mixes. Changes in dynamic networks such as batters are characterized by changes in tangent delta. The degree of elasticity is characterized by tangent delta value less than two (12). Single acting baking powder formulations generally had higher loss tangent values and showed greater loss of leavening potential than did those with double acting baking powder. Elasticity ($\tan\delta < 0.55$) was also highly correlated with gas production ($R = 1.0$) for all formulations (control, dry-blended, or coencapsulated).

Plots of measured dynamic viscosity of the flour and encapsulated butter oil dough to constrained oscillatory frequency are shown in Figure 2. The complex viscosity

Table I. Formulations for Muffins[a]

Product/Component	Control	F50 Formulation[b]	S50 Formulation[c]
All-purpose flour	100	76.4	100
Sucrose	21.1	21.1	–
F50	–	43.4	–
S50	–	–	43.4
Vegetable shortening	21.1	–	–
Fluid whole milk	75.6	75.6	75.6
Water	5.8	7.0	4.5

[a] Baking was done at 204°C for 24 min. All formulations contained the same amount of baking powder, salt (4.3%) and beaten liquid whole egg (26.0%), flour basis. Vegetable shortening was melted before blending into the dough.
[b] Butteroil encapsulated in flour (50%).
[c] Butteroil encapsulated in sucrose (50%).

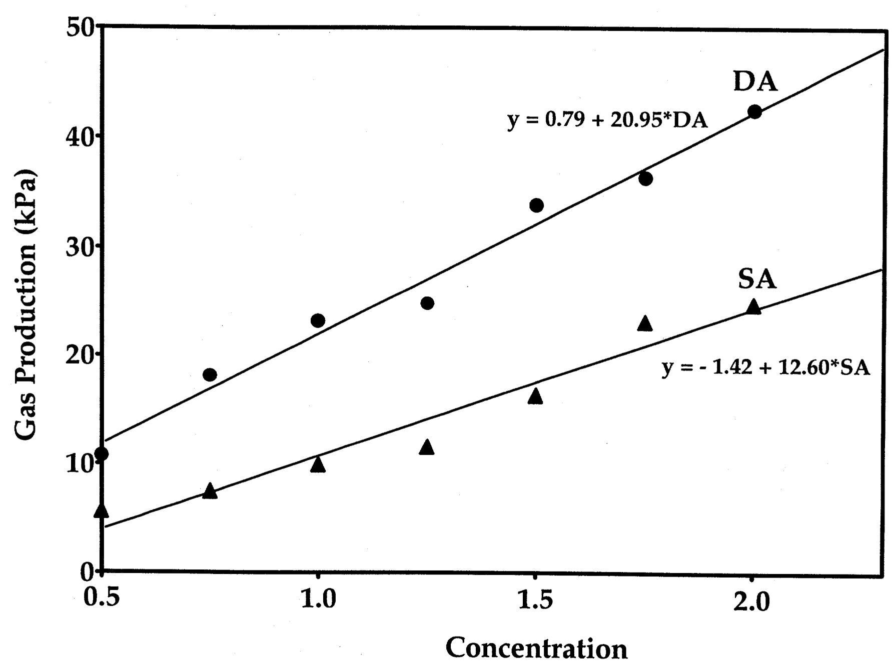

Fig. 1. Relative gas production by concentration of single-acting and double-acting baking powders.

Table II. Rheological Properties of Batters

Sample[a]	Gas Production (mm·Hg)	Complex Batter Viscosity (Poise)	Loss Tangent (tanΔ)
SCSA	41.42 a[b]	30,505 a	0.522 a
SBSA	45.45 a	23,495 b	0.517 a
SESA	20.62 b	35,670 a	0.519 a
SCDA	67.96 a	31,475 a	0.483 b
SBDA	66.16 a	19,445 c	0.509 a
SEDA	28.95 b	25,980 b	0.500 a
FCSA	24.53 b	31,370 b	0.496 b
FBSA	41.33 a	23,660 b	0.515 a
FESA	12.38 b	45,315 a	0.506 ab
FCDA	53.80 ab	27,145 ab	0.476 a
FBDA	70.28 a	24,140 b	0.433 b
FEDA	40.80 b	39,075 a	0.466 a
Pooled SD	7.80	50	0.07

[a] S = sucrose, F = flour, C = control, B = blended, E = co-encapsulated, SA = single acting, DA = double acting.
[b] Letters represent Duncan's mean separation within a column and within type of baking powder. Numbers with same letters are not significantly different.

Table III. Physical Properties of Baked Muffins

Sample[a]	Moisture (%)	Volume[b] (cm^3/g)	Expansion (mm)	Peak Breaking Force (N)
SCSA	32.7 ab[c]	2.34 b	66.4 a	0.61 b
SBSA	30.5 b	2.56 a	65.9 ab	0.34 c
SESA	33.6 a	1.54 c	62.5 b	0.90 a
SCDA	33.5 ab	2.45 a	66.0 a	0.47 b
SBDA	29.9 b	2.52 a	66.8 a	0.38 c
SEDA	35.2 a	1.23 b	61.1 b	3.73 a
FCSA	32.5 a	2.37 b	66.7 a	0.66 b
FBSA	32.5 a	2.45 a	63.6 a	0.42 b
FESA	33.3 a	1.65 c	61.6 a	0.21 a
FCDA	32.7 a	2.44 a	66.4 a	0.53 b
FBDA	32.0 a	2.50 a	66.8 a	0.40 b
FEDA	33.2 a	1. 19 b	63.0 a	3.18 a
Pooled SD	1.1	0.1	1.3	0.1

[a] S = sucrose, F = flour, C = control, B = blended, E = co-encapsulated, SA = single acting, DA = double acting.
[b] Specific volume obtained through rapeseed displacement test.
[c] Letters represent Duncan's mean separation within type of baking powder. Numbers with same letters are not significantly different.

(η*) is frequency dependent and suggests power law behavior. This pattern of flow is consistent with flow behavior of bread and dough systems, where the storage modulus is generally higher than the loss modulus (13). Properties of flour-gluten dough blends analyzed by dynamic rheometry showed that adding pregelatinized starch resulted in an increase in *G′* and a decrease in tangent delta. These rheological changes are proportional to the dough's starch content (14). The decrease in tangent delta in the muffin batters that contained coencapsulated ingredients is similar to that observed when adding pregelatinized starch to dough. This may explain some effects of $NaHCO_3$ on the flour in the encapsulation process, which resulted in a decrease in the specific volume of baked muffins made with coencapsulated $NAHCO_3$ (6).

Baked Muffins

The moisture content and physical properties of baked muffins are presented in Table III. Generally, as the amount of moisture retained increased, the specific volume of the muffins decreased. Generally, the muffins with lower specific volume had a harder texture as shown by higher peak force in Newtons. Moisture content of the coencapsulated muffins was significantly ($P < 0.05$) higher than that of the dry-blended for the sucrose formulations. The coencapsulated products (sucrose) showed higher moisture retention than their controls but the difference was not significant. The loss of CO_2 interfered with muffin matrix formation retarding moisture loss and rise in the oven. In both the standard and blended formulations, expansion and increased moisture loss improved the product volume.

The specific volume of the blended formulations is significantly higher than that for most other formulations. In the coencapsulated formulations, muffins with the SA baking powder were significantly higher in volume than were muffins baked with the DA ($P < 0.05$). Similar trends were observed with the measured height of the coencapsulated products (Fig. 3). Formulations of blended products exhibited significantly ($P < 0.05$) softer texture. The encapsulation process in the blended products, as reported earlier (4), improves the texture and volume of baked products, especially with the formulation made from butter oil encapsulated in flour.

The chroma of the baked muffins is presented in Figure 4. Blended products generally exhibited a higher chroma indicator than the controls, with the muffins containing SA baking powder browning less than those containing DA. The coencapsulated products were not completely baked in the time chosen and showed less browning ($P < 0.05$) than other formulations.

Color, volume, and structural integrity were significantly affected by the moisture dynamics with the coencapsulated powders. It is evident that, to improve the quality for instant mixes containing coencapsulated powders, adjustments for the

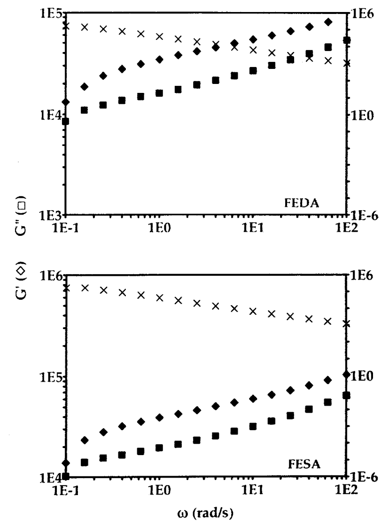

Fig. 2. Typical dynamic viscoelastic response of co-encapsulated muffin dough to frequency sweeps. FEDA: co-encapsulated flour and double-acting baking powder. FESA: co-encapsulated flour and single-acting baking powder.

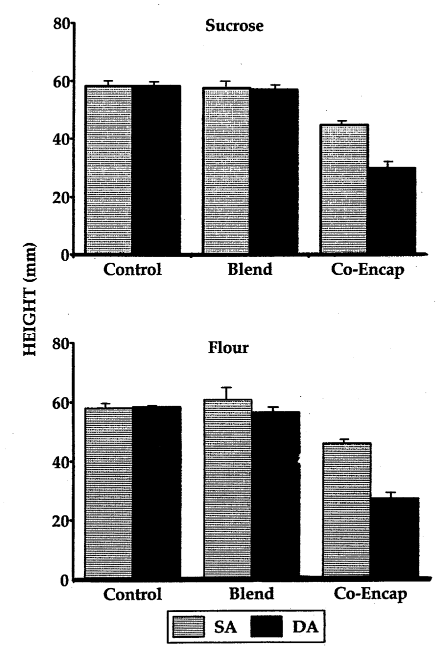

Fig. 3. Raised height of baked muffins.

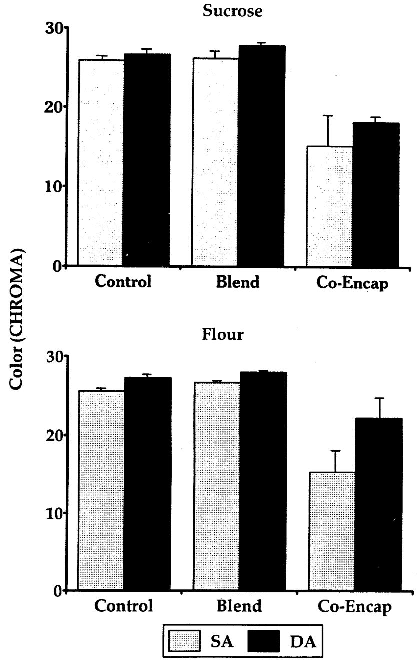

Fig. 4. Color of baked muffins.

loss of CO_2 are needed. Increases in volume with butter oil encapsulated in flour had been noted earlier when used as a shortening substitute in baking biscuits, cookies, and muffins (5). Coencapsulation is a step toward creating an instant bakery mix that, when optimized, may deliver a superior quality product.

CONCLUSIONS

Coencapsulation of powders containing butter oil and baking powders produced an instant baking mix but wth poor rising power. This led to noticeable changes in batter consistency. The coencapsulation process needs improvement in the spray drying step, which leads to loss of leavening power and excessive moisture retention in the baked product.

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REFERENCES

1. Onwulata, C. I., Smith, P. W., Craig, J. C., Jr., and Holsinger, V. H. Physical properties of encapsulated milkfat powders. J. Food Sci. 59:316, 1994.
2. Young, S. L., Sarda, X., and Rosenberg, M. Microencapsulating properties of whey proteins. 1. Microencapsulation of anhydrous milkfat. J. Dairy Sci. 76:2868, 1993.
3. Onwulata, C. I., Smith, P. W., Konstance, R. P., and Holsinger, V. H. Some baking properties of encapsulated milkfat. Food Technol. 49:82, 1995.
4. Snow, N. S., Townsend, F. R., Bready, P. J., and Shimmin, P. D. Manufacturing conditions for butter powder 2. The effect of manufacturing conditions on baking performance. Aust. Dairy Technol. 22:125, 1967.
5. Onwulata, C. I., Konstance, R. P., and Holsinger, V. H. Flow properties of encapsulated milkfat powders as affected by flow agent. J. Food Sci. 61:1211, 1996.
6. Dorko, C. L., and Penfield, M. P. Melt point of encapsulated sodium bicarbonates: Effect on refrigerated batter and muffins baked in conventional and microwave oven. J. Food Sci. 58:574, 1993.
7. Dziezak, J. D. Microencapsulation and encapsulated ingredients. Food Technol. 42:136, 1988.
8. Aguilera, J. M., Xiong, Y. L., and Kinsella, J. E. Viscoelastic properties of mixed dairy gels. Food Res. Int. 26:11, 1993.
9. American Association of Cereal Chemists. Method 22-11, Diastatic Activity—Pres-sure Meter Method. *Approved Methods of the American Association of Cereal Chemists,* 9th ed. The Association, St. Paul, MN, 1995.
10. AOAC. *Official Methods of Analysis, 14th ed. Association of Official Analytical Chemists.* The Association, Washington, DC, 1984.
11. Matz, S. A. *Chemistry and Technology of Cereals as Food and Feed.* Van Nostrand Reinhold, New York, 1991.
12. Ferry, J. D. *Viscoelastic Properties of Polymers.* John Wiley & Sons, New York, 1980.
13. Abdelrahman, A., and Spies, R. Dynamic rheological studies of dough systems. In: *Fundamentals of Dough Rheology.* H. Faridi and J. M. Faubion, Eds. AACC, St. Paul, MN, 1986.
14. Dreese, P. C., Faubion, J. M., and Hoseney, R. C. Dynamic rheological properties of flour, gluten, and gluten-starch doughs. 1. Temperature-dependent changes during heating. Cereal Chem. 65:348, 1988.