

Effects of Microencapsulated High-Fat Powders on the Empirical and Fundamental Rheological Properties of Wheat Flour Doughs

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ABSTRACT

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Microencapsulated high-fat powders are a healthy and convenient alternative to fats normally used in cereal-based products. In powder form they are easier to use than block fat. Microencapsulation involves dispersion of the fat using homogenization. The globules are then fixed by spray-drying. Empirical and fundamental rheological tests were conducted on doughs containing commercial vegetable fat and four microencapsulated high-fat powders. The doughs were compared with a standard dough containing no fat. The powders contained 70% vegetable fat or milk fat. The encapsulating agent used was either sodium caseinate or whey protein concentrate (5–10%). Sucrose or lactose were also present in the powders (20–25%). The powders were manufactured at low- or high-pressure

homogenization. Farinograph and extensigraph tests were performed on all doughs. Dynamic oscillation tests were conducted in the linear viscoelastic region of the dough. Addition of fat and microencapsulated high-fat powders produced using low-pressure homogenization reduced the complex modulus of the doughs. The results showed an increase in phase angle with incorporation of commercial fat and the microencapsulated high-fat powders. Scanning electron microscopy was conducted to examine the effects of the additives on dough structure. This study demonstrated that microencapsulated high-fat powders, especially powders produced using low-pressure homogenization, had some beneficial effects on dough rheology when compared with doughs produced with commercial fat.

The addition of dairy ingredients to bakery products to improve the quality and nutritive value has been practiced for many years (Renz Shauen and Renner 1987). Traditionally empirical tests (e.g., farinograph, extensigraph) were used to characterize dough rheology (Hoseney and Rogers 1990). However, Bloksma and Bushuk (1988) found that it was difficult to detect differences between doughs with or without added fat using the farinograph or extensigraph at 30°C. According to Szczesniak (1988), these traditional dough testing methods are only single-point measurements and do not provide information on the detailed physical properties of doughs. Doughs are viscoelastic substances, and thus dynamic oscillatory rheometry has been used extensively in the past 30 years to study dough at a fundamental level (Faubion and Faridi 1990). The flow and deformation properties of dough are considered important indicators of the quality of the baked products (Menjivar 1990). Dynamic oscillatory tests can measure the rheological properties of dough at different frequencies. The chief advantage of this method is the ability to differentiate between the storage and loss modulus. The applied stress and the resultant strain can be measured at each frequency. The complex modulus and viscosity can be calculated using these two values and the phase angle between them (Weipert 1990).

The dairy ingredients used in our study were microencapsulated high-fat powders. Microencapsulation involves the dispersion of the fat globules in an emulsified state using homogenization. The microparticles or globules <1 µm in diameter are then fixed by spray-drying. The microencapsulated high-fat powders produced are free flowing and allow easy handling (Keogh and O'Kennedy 1999). Microencapsulation of materials susceptible to oxidation retards oxidation significantly (Anandaraman and Reinicus 1986). Thus, microencapsulation of fat has the potential to increase its oxidative stability and convert it into a stable powder (Moreau and Rosenberg 1996). These powders were added as a replacement for bakery shortening. Examination of the effects of added fat on rheological properties has not received widespread attention in the literature, despite the regular addition of fat in breadmaking (1–

5%) (Bloksma and Bushuk 1998). Addition of shortening to baked products increases product volume (Junge and Hoseney 1981, Hoseney 1994, Stauffer 1988). Junge and Hoseney (1981) found that doughs containing 3% fat expanded for a longer time than those without fat in a resistance oven, explaining the larger volume.

The objective of our study was to examine the effects of microencapsulated high-fat powders on various aspects of dough rheology. The farinograph was used to measure water absorption and degree of softening. Resistance to extension at 5 cm (R_{5cm}) was measured using the extensigraph. A rheofermentometer was used to measure dough development height. Fundamental rheological measurements were performed with a controlled stress rheometer. Dynamic oscillation tests were conducted in the linear viscoelastic response region of the dough. A strain sweep test was performed in advance to ensure measurements took place in this region. Scanning electron microscopy was used to give a visual indication of the effects of the commercial vegetable fat and the microencapsulated high-fat powders on dough structure.

MATERIALS AND METHODS

Commercial plain wheat flour (Baker's Flour, Odlum Group, Dublin, Ireland), (13.2% protein) was used in all the trials. Commercial bakery shortening (Stork, Vanden Bergh Foods Ltd, Brooke House, Crawley, UK) was used for comparison with the high-fat powders. The microencapsulated high-fat powders (Table I) were obtained from Teagasc, Dairy Products Research Centre, Moorepark, Fermoy, Cork, Ireland. Vacuum-dried salt (Salt Union, Weston Point, Runcorn, Cheshire, UK) was also incorporated into the dough.

The dough recipe (based on flour weight) was 100% flour, 60% water (fixed water addition), 2% salt, 5% commercial fat (80% fat), or 5.7% microencapsulated high-fat powder (70% fat). Flour moisture was determined by ICC standard method No. 110/1 (ICC 1995). The control dough (flour, water, and salt) and doughs with the commercial fat and the microencapsulated high-fat powders were tested by farinograph according to the ICC standard method No. 115/1. Each result is the average of two measurements. The control dough (flour, water, and salt) and doughs with additives were tested by extensigraph according to the ICC standard method No. 114/1. Each result is the average of three measurements. Oscillation measurements were performed with a controlled stress rheometer (Bohlin Rheology AB, Lund, Sweden). Doughs were mixed in a 10-g mixing chamber (Glutomatic 2200, Falling Number AB, Stockholm, Sweden) and allowed to rest in an enclosed environment for 15 min before being placed between parallel plates (40 mm

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diameter, 2 mm gap). They were then allowed to rest a further 5 min before oscillation. Measurements were made at 16 frequencies (0.01–10 Hz) and the target strain was 0.1%. Each result is the mean of five samples. Phase angle and complex modulus (G^*) were also calculated.

Dough development height was measured using a rheofermentometer (F3, Chopin, France). Doughs were mixed in a farinograph mixer, 300 g of dough was used in each test. Dough development was measured for 1.5 hr. The average of two measurements was taken in each case.

Scanning Electron Microscopy

The doughs were mixed as for the oscillation measurements (same recipes). Immediately after mixing, they were cut into pieces and frozen at -20°C and freeze-dried for 24 hr (Freezemobile 12SL, Virtis Co., Gardiner, NY). The samples were then fractured to expose the inner surfaces (Varriano-Marston 1977) and mounted onto specimen stubs using silver paint and sputter-coated with gold at 2.5 kV for 120 sec in a coating unit (Polaron E5100). The preparations were viewed using a JEOL-35 scanning electron microscope (JEOL House, Welwyn Garden City, Heets, UK) at an accelerating voltage of 15 kV. The preparations were photographed and enlarged using the De Vere 504 enlarger (De Vere House, Beckenham Road, Kent, UK).

Statistical Analyses

Analysis of variance (ANOVA) was applied to the data obtained from the rheological tests using a statistical software package (SPSS V8.0.0). Tukey's honestly significant difference (HSD) posthoc test was used to determine significant differences. All results are from doughs containing added whey protein concentrate (WPC75-1, WPC75-2) or sodium caseinate (NaCas-1,

NaCas-2) or the commercial block fat (Std-2) or dough containing no fat (Std-1). Results from the other powders tested (Table I) were within these ranges and were statistically similar.

RESULTS AND DISCUSSION

Farinograph

Figure 1 shows that the addition of microencapsulated high-fat powders to doughs increased the water absorption of the dough when compared to Std-1 and Std-2, which would be beneficial in baking applications. The protein type in the powders (Table I) did not have a significant effect on water absorption at this concentration. According to Kinsella (1984), sodium caseinate powders absorb water excessively in flour systems. However, these powders contained only 5 or 10% protein which accounts for only 0.15 or 0.3% of the overall formulation. Thus, it was the protein content combined with the sugars, sucrose, or lactose in the powders that increased the water absorption.

Degree of softening is a measure of dough tolerance to mixing. Std-1 had the lowest degree of softening (Fig. 2). All additives increased this effect. WPC75-2 and NaCas-2 performance was similar to that of Std-2. These powders were manufactured at low-pressure homogenization and had more free fat and thus acted similarly to block fat in the dough.

Extensigraph

Std-1 had the highest $R_{5\text{cm}}$ values at 45, 90, and 135 min. All additives had a softening effect on the dough (Table II). Empirical tests such as the extensigraph do not detect the presence of fat in doughs at 25°C (Bloksma and Bushuk 1988). However, our findings showed that Std-1 had significantly higher $R_{5\text{cm}}$ values (P

TABLE I
Components of Prepared Dough Samples

Dough ^a	Protein %	Fat	Homogenized Pressure	Sugar
Std-1		None		
Std-2		Vegetable ^b		
WPC75-1	10	Milkfat ^c	45 Mpa	Sucrose
WPC75-2	5	Milkfat	4 Mpa	Lactose
WPC75-3	5	Vegetable ^d	45 Mpa	Sucrose
WPC75-4	10	Vegetable	45 Mpa	Lactose
WPC75-5	10	Vegetable	4 Mpa	Sucrose
NaCas-1	10	Vegetable	45 Mpa	Sucrose
NaCas-2	10	Milkfat	4 Mpa	Lactose
NaCas-3	5	Vegetable	4 Mpa	Lactose
NaCas-4	5	Milkfat	4 Mpa	Sucrose
NaCas-5	5	Milkfat	45 Mpa	Lactose

^a Standard dough (Std) and doughs with added whey protein concentrate high-fat powders or sodium caseinate high-fat powders.

^b Commercial partially hydrated block fat.

^c Milkfat fat in powder form.

^d Vegetable blend in powder form.

TABLE II
Analysis of Variance for Resistance to Extension at 5 cm^a

Sample Type ^b	45 min	90 min	135 min
Std-1	435a ^c	570a	660a
Std-2	330c	475b	540b
WPC75-1	315c	430c	440d
WPC75-2	215d	305d	260e
NaCas-1	355b	480b	510c
NaCas-2	215d	260e	210f

^a Tukey's HSD using harmonic mean sample size = 3.

^b Standard dough (Std) and doughs with added whey protein concentrate high-fat powders or sodium caseinate high-fat powders.

^c Means followed by different letters in the same column are significantly different ($P < 0.05$).

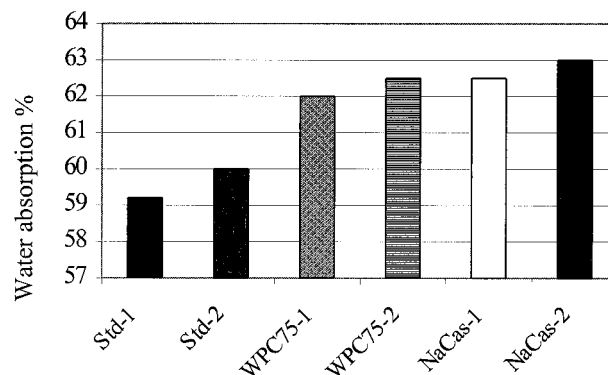


Fig. 1. Influence of commercial fat and four microencapsulated high-fat powders on water absorption in standard dough (Std) and doughs with added whey protein concentrate (WPC75) or sodium caseinate (NaCas).

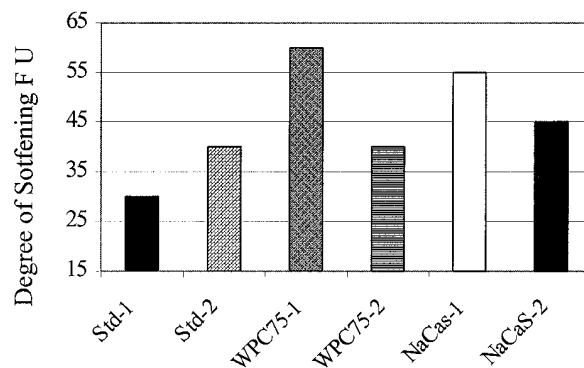


Fig. 2. Effect of commercial fat and four microencapsulated high-fat powders on degree of softening (farinograph units) in standard dough (Std) and doughs with added whey protein concentrate (WPC75) or sodium caseinate (NaCas).

< 0.05) than Std-2 at three time intervals. Std-2 had significantly higher values ($P < 0.05$) than doughs containing WPC75-2 and NaCas-2. This indicates that these microencapsulated high-fat powders are reducing R_{5cm} more than the commercial fat, giving a less stiff dough with greater potential for expansion. The better distribution of the fat in free flowing powder form throughout the dough helps enhance its effect on the R_{5cm} at each of the time intervals. WPC75-1 and NaCas-1 also reduced R_{5cm} despite the lower free fat available in these powders (due to the high-pressure homogenization used in the manufacture). The protein fractions in these powders may also have a lowering effect on the R_{5cm} values, however this could not be confirmed in the literature.

Complex Modulus

Std-1 had the highest G^* over the whole frequency range (Fig. 3), indicating that the addition of fat in any form reduces G^* . WPC75-1 and NaCas-1 also had high values for G^* that were similar at all frequencies (results shown at 10 Hz, Table III). This indicates that protein type used in the powder manufacture at this concentration does not have a significant effect on the G^* . The difference between WPC75-2 and NaCas-2 was only significant ($P < 0.05$) at higher frequencies. Doughs containing both of these powders had significantly lower G^* (Table III, $P < 0.05$) than doughs containing WPC75-1 and NaCas-1. Std-2 had values for G^* similar to WPC75-2 at all frequencies. According to Fu et al (1997), both the elastic and viscous moduli are reduced by the addition of fat up to a saturation addition level. This explains why Std-2, WPC75-2, and NaCas-2 had the lowest value for G^* . The high-pressure homogenization (Table I) used in WPC75-1 and NaCas-1 reduced the level of free fat in the dough, explaining why these doughs have higher G^* than doughs containing WPC75-2 or NaCas-2.

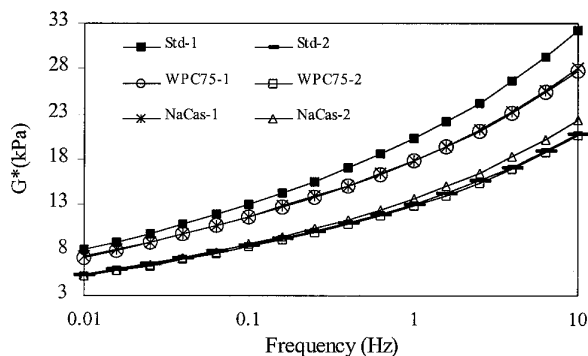


Fig. 3. Influence of commercial fat and four microencapsulated high-fat powders on complex modulus (G^* , 0.01–10 Hz) in standard dough (Std) and doughs with added whey protein concentrate (WPC75) or sodium caseinate (NaCas).

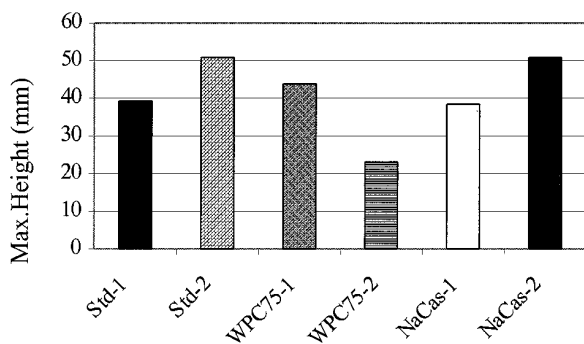


Fig. 4. Effect of commercial fat and four microencapsulated high-fat powders on dough development height. Standard dough (Std) and doughs with added whey protein concentrate (WPC75) or sodium caseinate (NaCas).

Phase Angle

The differences in phase angle between the samples were significant ($P < 0.05$) only at higher frequencies (results shown at 10 Hz, Table III). According to Weipert (1992), stiff or bucky doughs have lower values for $\tan \delta$ and thus have lower phase angles. This is in accordance with our findings. Addition of the commercial fat to Std-2 reduced the elasticity of the dough. However, this effect was not seen in doughs containing WPC75-1 or NaCas-1 due to the inability of the fat in the powders produced using high-pressure homogenization (Table I) to interact with starch and protein in the dough. Elasticity is one of the most important factors in the quality of the finished product as it affects the gas-holding capacity of the dough as well as other factors (Bloskma 1990). Doughs containing WPC75-2 and NaCas-2 had phase angles similar to Std-2 ($P < 0.05$). The protein type used in powder manufacture does not have a significant effect on phase angle. A perfectly elastic solid has a phase angle of zero, thus, the lower the phase angle the more elastic the dough (Walker and Hazelton 1996). Doughs containing WPC75-1 and NaCas-1 had the lowest values for phase angle (lower than Std-1) due to the extra water absorbed by these powders because water addition was kept constant for each recipe. This indicates that these samples had the highest elasticity. There were no significant differences ($P < 0.05$) between these samples.

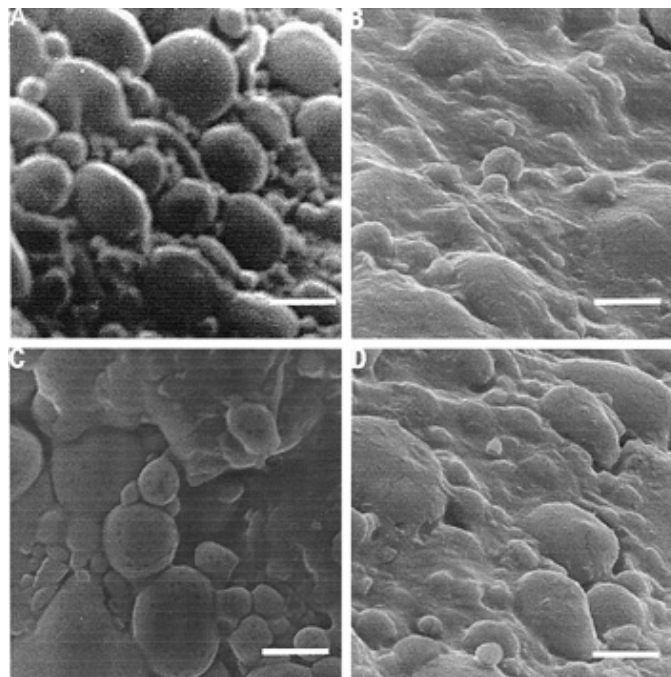


Fig. 5. Scanning electron micrograms of standard dough (Std) and doughs with added whey protein concentrate (WPC75): A, Std-1; B, Std-2; C, WPC75-1 and D, WPC75-2. Bar = 10 μ m.

TABLE III
Effects of Additives on Fundamental Dough Rheology^a

Sample Type ^b	G' at 10 Hz (kPa)	Phase Angle at 10 Hz ($^\circ$)	Viscosity at 10 Hz (kPa/sec)
Std-1	32,217a ^c	23.5b	513a
Std-2	20,757c	23.9ab	330c
WPC75-1	27,740b	22.9c	441b
WPC75-2	20,600c	24.0a	328c
NaCas-1	27,980b	22.9c	445b
NaCas-2	22,260c	24.0a	354c

^a Tukey's HSD using harmonic mean sample size = 5

^b Standard dough (Std) and doughs with added whey protein concentrate high-fat powders or sodium caseinate high-fat powders.

^c Means followed by different letters in the same column are significantly different ($P < 0.05$).

Viscosity

Decrease in viscosity over an increasing frequency range shows the shear thinning of doughs (Wehrle et al 1997). Std-2 and doughs containing WPC75-2 and NaCas-2 (manufactured at low-pressure homogenization, Table I) had similar values for viscosity ($P < 0.05$, Table III). The presence of free fat in the doughs reduces viscosity. Results are shown at 10 Hz, but similar trends occurred over the entire frequency range. Std-1 had the highest value for viscosity because no fat was present in this dough (Table III). Similar values were found for doughs containing WPC75-1 and NaCas-1. The values for these doughs were significantly higher than for doughs with NaCas-2 and WPC75-2. This was due to the lower levels of free fat in doughs with WPC75-1 and NaCas-1. Protein type at this concentration in the powders does not have a significant effect on viscosity.

Dough Development Height

Std-2 had the highest dough development height at 1.5 hr (Fig. 4). A high dough development height is an indicator of high loaf volume in subsequent baking trials. Doughs containing NaCas-2 had a development height similar to that of Std-2. Caseinates, and especially sodium caseinates, are excellent surfactants compared with whey proteins, which can be attributed to the amphiphilic structure (Kinsella 1984). WPC75-2 was manufactured at low-pressure homogenization also; thus, it would be expected to have a development height value similar to that of Std-2 due to the available fat. However, this dough collapsed under the 1.5-kg load placed on it in the fermentation vat, indicating that it had a weaker structure. This load would be far greater than pressures normally associated with proofing. Zadow and Hardham (1981) reported that doughs containing whey protein concentrate have a porous structure leading to a loss of gas when under stress, thus causing the collapse of the dough.

Scanning Electron Microscopy

Doughs containing WPC75-1 showed the same coarse structure as Std-1 (no added fat) (Fig. 5). Both these doughs show uncoated starch granules with no visible fat. This is due to the low free fat content in this powder manufactured with high-pressure homogenization (Table I). When the homogenization pressure is lowered, as with WPC75-2 (Table I), an increased release of fat in the dough is reflected in a similar coated dough structure, as is seen with the commercial block fat.

CONCLUSIONS

Microencapsulated high-fat powders provide a functional alternative to the use of block fat in wheat doughs and subsequently in bread. They are also easy to use and store. However the processing conditions and composition of the powders must be carefully chosen to optimize powder performance. These parameters affect the levels of free fat in the powders which determines their interactions in the dough. Farinograph results indicate that the powders do not absorb water excessively in the dough due to the low protein concentrations in the powders. All of the powders reduced R_{5cm} values. This indicates that the doughs are less elastic and would perform favorably in baking tests. Powders produced using low-pressure homogenization reduced G^* and increased phase angle. Doughs with these characteristics are slacker and more viscous than doughs with powders produced using high pressure. This

would allow for greater expansion on proofing. Scanning electron micrographs indicate that these powders do not impart the usual benefits associated with fat addition to the dough structure. However doughs containing powders produced using low-pressure homogenization had structures similar to doughs with commercial block fat added.

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