Studies on Frozen Doughs. IV. Effect of Shortening Systems on Baking and Rheological Properties[1]

Y. INOUE,[2] H. D. SAPIRSTEIN,[3] and W. BUSHUK[3]

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ABSTRACT

Effects of three types of shortening systems on baking and rheological properties of frozen doughs were studied. The first type included hydrogenated canola oil (control) and canola oil. Type 2 included control, control + 5% (oil basis) lysolecithin, control + 5% calcium stearoyl lactylate (CSL), and control + 5% diacetyl tartaric acid esters of monoglyceride (DATEM). Type 3 included control, water (40 and 60%) in control emulsion, and control (40 and 60%) in water emulsion. The amount of shortening in the dough formula was 10% (flour basis). Molded doughs were prepared by a short-time dough procedure and frozen at −20°C. After up to 10 weeks of frozen storage, the doughs were thawed, and replicate doughs were tested on the extensigraph and baked. Of the shortening systems tested, CSL, DATEM, and the two oil in water (O/W) emulsions produced a significant improvement in baking properties. The CSL and DATEM formulae resulted in significantly higher loaf volumes for the nonfrozen and one-day frozen dough treatments. There was no significant difference between these surfactants and the 40% O/W emulsion system after four weeks of frozen dough storage. Comparing all shortening systems after 10 weeks of frozen storage, the O/W emulsion systems were associated with the lowest final proof times and highest loaf volumes; gassing power was similar to that of the CSL and DATEM treatments. Most notable was the observation that for the O/W emulsion treatments, the loaf volumes hardly decreased during the extended frozen storage period. Results of this study showed that the loss in breadmaking potential of frozen doughs during storage can be mitigated by including in the formula a shortening system specially formulated for frozen doughs.

The use of frozen dough has become a viable alternative to conventional dough processing in today's in-store baking industry (Krumrei 1989). The baking potential of frozen doughs decreases with increasing frozen storage period or the number of freeze-thaw cycles. The loss of baking potential can be limited to some degree by adjustments in processing conditions (Merritt 1960, Lorenz 1974), formulation (Lorenz 1974, Marston 1978), type of yeast (Kline and Sugihara 1968, Hino et al 1987, Neyreneuf and Van Der Plaat 1991), type of flour (Neyreneuf and Van Der Plaat 1991, Inoue and Bushuk 1992), and oxidizing agents (Lorenz and Bechtel 1965, Hsu et al 1979, Inoue and Bushuk 1991).

Shortening systems, including fats, oils, and surface-active agents, are evolving for applications in chemically leavened and yeast-raised baked products (Knightly 1981). However, the effect of shortening systems in frozen doughs has received relatively less attention. Lorenz (1974) and Marston (1978) reported that the addition of a higher proportion of shortening improved the quality of breads from frozen doughs. Surface-active agents like sodium or calcium stearoyl lactylate (SSL or CSL) and diacetyl tartaric acid ester of monoglyceride (DATEM) have been shown to be effective in maintaining loaf volume and crumb softness of breads from frozen doughs (Marston 1978, Davis 1981, Varriano-Marston et al 1980, Wolt and D'Appolonia 1984). Hosomi et al (1992) showed that a hydrophilic sugar ester improved baking and rheological properties of frozen doughs.

In this article, the effectiveness of three groups of shortening systems (type of oil, type of surface-active agent added to the oil, and type and composition of emulsion system) in maintaining baking and rheological properties of dough subjected to extended frozen storage are reported.

[1]Publication 234, Department of Food Science, University of Manitoba, Winnipeg, Canada.
[2]The Japan School of Baking, Tokyo, Japan.
[3]Department of Food Science, University of Manitoba, Winnipeg, Canada.

MATERIALS AND METHODS

Shortening Samples

Three types of shortening systems were used with hydrogenated canola oil (m.p. 31°C) as the control; group I (type of oil): 1) control and 2) canola oil; group II (type of surface-active agent added): 1) control, 2) lysolecithin (LL) 5 g/95 g of control, 3) calcium stearoyl-2-lactylate (CSL) 5 g/95 g of control, and 4) diacetyl tartaric acid esters of monoglyceride (DATEM) 5 g/95 g of control; group III (type of emulsion system and amount of water added): 1) control, 2) water in oil emulsion, 40% water + 60% control (40% W/O), 3) water in oil emulsion, 60% water + 40% control (60% W/O), 4) oil in water emulsion, 40% water + 60% control (60% O/W), and 5) oil in water emulsion, 60% water + 40% control (40% O/W). Polyglycerol ester of interesterified ricinoleic acid (PEIR) (1% shortening basis) and polyglycerin monostearate (PGMS) (2% shortening basis) were used as emulsifiers for the preparation of the W/O and O/W emulsions, respectively.

All the shortening components used were provided by Nippon Oil Co. Ltd. (Tokyo). LL used was Elmyzer A, Kyowa Hakko Kogyo Co. Ltd. (Tokyo); CSL was from Riken Vitamin Co. Ltd. (Tokyo); DATEM was Panodan AM from Grinsted Products Inc. (Denmark), and PEIR was Sun Soft 818H with a hydrophilic-lipophilic balance (HLB) value of 2.5 from Taiyo Kagaku Co. Ltd. (Tokyo). PGMS used was Emulsy MS with HLB value of 13 from Riken Vitamin Co. Ltd. (Tokyo).

To prepare the W/O emulsions, PEIR (1% shortening basis) was dissolved in control oil heated at 70°C. Water (40 or 60%, shortening basis) was emulsified in the oil phase with stirring for 20 min at 60°C. The resulting emulsion was rapidly cooled to 15°C and plasticized in a votator (Nikkiso Co. Ltd., Tokyo). The O/W emulsions were similarly prepared by dissolving PGMS (2% shortening basis) in water heated at 60°C. Control oil (preheated at 60°C) was emulsified in the water phase with stirring for 20 min at 60°C. The resulting O/W emulsions were homogenized in a homogenizer (Sanwa Kikai Co. Ltd., Shizuoka) using 180 L/hr flow rate and 150 kg/cm^2 of pressure, followed by cooling to 15°C using an ice water bath.

Flour Sample

The flour was an untreated straight-grade flour milled from a sample of No. 2 Canada Western Red Spring wheat of the 1990 crop year. Its protein (N × 5.7) and ash contents were 13.5 and 0.45%, respectively (14% mb). Protein and ash determinations were made according to AACC (1983) methods 46-12 and 08-01, respectively.

Yeast Sample

Compressed baker's yeast (Fleischmann's Yeast Ltd., Toronto, ON) was used within one week of its receipt.

Dough Formulation

The dough formula was: 100% flour, 5% yeast, 4% sugar, 1.5% salt, 10% shortening, 100 ppm ascorbic acid, and 59% water. Concentrations are based on flour. In experiments with group III shortening systems, the amount of each type of shortening added was adjusted to a total fat level of 10%. The amount of water added in the shortening emulsion was subtracted from the water added to the dough.

Dough Mixing

A short-time dough mixing procedure described previously (Inoue and Bushuk 1991) was used. For each batch, doughs containing 200 g of flour were mixed in a GRL-200 mixer equipped with a GRL energy input meter (Kilborn 1979). Doughs were mixed just beyond the peak development, as indicated by the mixing curve. Mixed doughs were divided into two 160-g pieces and fermented for 20 min in a fermentation cabinet controlled at 30°C and 90–95% rh. Each of the two fermented dough pieces represented a single replicate for different treatments or tests. Three replicate fermented dough pieces (from different dough batches) for each shortening system were molded on a GRL sheeter-molder (Kilborn and Irvine 1963), panned, and then final-proofed in the fermentation cabinet for 55 min. The height of the proofed dough pieces was measured. The average height of the three replicated doughs was subsequently used as the "standard" proofing height for the analogous frozen doughs. The average standard proofing height over all shortening systems was 102 ± 1 mm. Loaves were baked at 218°C for 23 min. After 30 min of cooling, loaf volume was determined by rapeseed displacement.

Preparation of Frozen Doughs

Dough pieces were frozen at −20°C immediately after molding and stored at −20°C. After one day, three dough pieces for each shortening system were thawed at −2°C for ~15 hr, panned, and final-proofed to the standard proofing height. This procedure was repeated after four and 10 weeks of frozen storage. The average proof time for three replicate dough pieces was recorded as the final proof time for that treatment. After final proofing, the doughs were baked, and loaf volumes were measured.

Extensigraph Procedure for Frozen Dough

The extensigraph procedure described previously (Inoue and Bushuk 1991) was used, with some minor modifications. Dough pieces (160 g) (same weight as in baking) were molded into 16.0 cm long cylinders and clamped into the modified dough holder (Kilborn and Preston 1982). The test pieces were proofed in the fermentation cabinet (55 min for nonfrozen doughs and 80 min for thawed doughs) and stretched using the straight stretching bar. Nonfrozen and thawed doughs were at the same temperature (30°C) after proofing. For each shortening system, average results and standard deviations for three replicated dough pieces are reported.

Gassing Power

Gassing power was measured as previously described (Inoue and Bushuk 1992). Molded nonfrozen and thawed frozen doughs were remixed in the GRL-200 mixer for 5 min at 90 rpm. During the remixing, the mixing bowl temperature was controlled at 30° ± 0.5°C. The remixed dough (30 g) was placed in a gassing power pressure meter (calibrated in mm Hg) and allowed to ferment for 90 min at 30°C (AACC method 22-13, 1983). Two replicated samples were tested for each treatment.

Statistical Analysis

Analysis of variance using the general linear models procedure with *t*-tests for treatment means comparison (SAS Institute, Cary, NC) was used to evaluate the data.

RESULTS AND DISCUSSION

Data for the technological properties of doughs formulated with different shortening systems and subjected to frozen storage periods are presented graphically in Figures 1–6. Figures 1–3 show the effect of different shortening systems for each frozen storage period. Figures 4–6 show the effect of frozen storage period for each shortening system.

Effect of Type of Oil

Final proof time of control (hydrogenated canola oil) formulated doughs increased, and loaf volume decreased with increasing frozen storage time (Fig. 1). Maximum extensigraph resistance of the doughs also decreased, and extensibility increased slightly (Fig. 2). Gassing power of the doughs did not change after one day of storage but decreased significantly after four and 10 weeks (Fig. 3). These results are generally consistent with the results of a previous studies (Inoue and Bushuk 1992, Inoue et al 1994) in which a lean dough formulation (1.5% of shortening) was used. However, changes in the baking and rheological properties of the doughs observed in this study are smaller than those observed in the previous studies. It appears that the higher shortening content (10%) used in this study protected the dough structure,

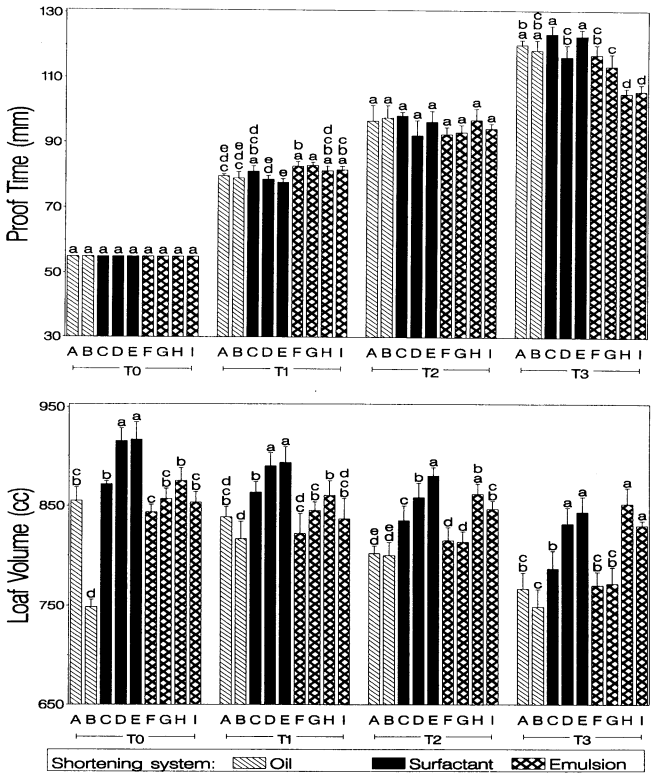

Fig. 1. Effect of shortening system grouped by frozen dough storage period on final proof time and loaf volume. T0 = nonfrozen, T1 = frozen for one day, T2 = frozen for four weeks, T3 = frozen for 10 weeks. A = hydrogenated canola oil (control), B = canola oil, C = lysolecithin, D = calcium stearoyl-2-lactylate, E = diacetyl tartaric acid esters of monoglyceride, F = water in oil emulsion (40% water + 60% control), G = water in oil emulsion (60% water + 40% control), H = oil in water emulsion (40% water + 60% control), I = oil in water emulsion (60% water + 40% control). Within each frozen dough storage period, histogram bars annotated with the same letter denote mean values that are not significantly different ($P < 0.05$).

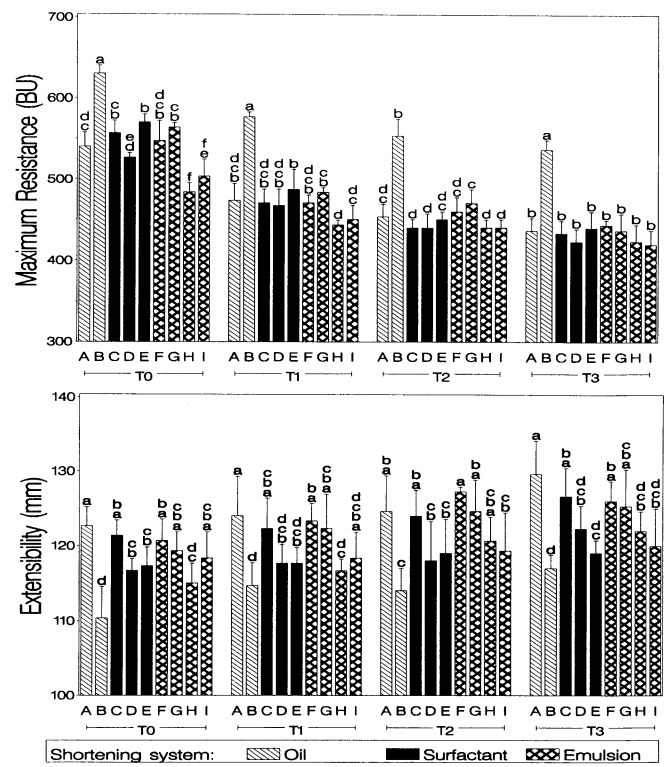

Fig. 2. Effect of shortening system grouped by frozen dough storage period on extensigraph maximum resistance and extensibility. Identity of bars and abbreviations as in Fig. 1.

as suggested by Marston (1978).

Loaf volume of the breads baked from the nonfrozen doughs containing canola oil was significantly ($P < 0.05$) lower than that of the control (Fig. 1). This well-known result is caused by the lack of solid fat in the oil. Baker and Mize (1942) suggested that solid fats, when present in sufficient quantity, improved the gas retention of dough by essentially plugging holes in cell walls; this hypothesis was later confirmed by Baldwin et al (1963). In addition, Tsutsui (1989) reported that the low affinity of canola oil for gluten when compared with that of hydrogenated canola oil is a possible cause of the lower loaf volume of breads containing the untreated canola oil. In this study, extensigraph results of the nonfrozen doughs containing canola oil showed a very high maximum resistance and low extensibility (Figs. 2 and 5) compared with those of the control. These results indicate that canola oil produces doughs that are bucky, probably due to a lack of an ability of the oil to lubricate the dough structure. The buckiness would limit ovenrise and, hence, yield lower loaf volume. It is interesting that the loaf volume of the dough containing canola oil increased significantly after one day of frozen storage while that of the control decreased (Fig. 4). It appears that freezing decreased the resistance and increased the extensibility (Fig. 5) and thereby produced an increase in loaf volume. The final proof times of control and canola oil doughs were not significantly different (Fig. 1). The gassing power of canola oil doughs was slightly higher than that of the control after 10 weeks of frozen storage (Fig. 3). Loaf volume of bread containing canola oil decreased at approximately the same rate as that of the control from one day to 10 weeks of frozen storage (Figs. 1 and 4).

Effect of Type of Surface-Active Agent

The average standard proof heights for the nonfrozen doughs formulated with CSL and DATEM were 104 ± 0 and 103.3 ± 0.6 mm, respectively (Table I). This compares with an average value of 101.7 ± 0.3 mm for the other shortening systems. While the difference was small in absolute terms, it was statistically ($P < 0.05$) and practically significant considering the test baking conditions with 160 g of dough. Not surprisingly, the addition of CSL and DATEM to the control (hydrogenated canola oil) gave a significant ($P < 0.05$) increase in loaf volume for nonfrozen doughs (Fig. 1). The use of LL did not produce a comparable effect. The improving effect of CSL and DATEM is attributed to their dough strengthening and stabilizing effects (Tsen and Weber 1981). These surface-active agents appear to interact with gluten proteins to form a glutenin-(surface-active agent)-gliadin complex (Aidoo and Tsen 1973) or interact with gluten proteins and thereby improve the stability of the Grosskreutz bilayer (Stutz et al 1973). However, the extensigraph results of the present study on nonfrozen doughs showed only a slightly higher maximum resistance for doughs containing DATEM and a lower extensibility from both CSL and DATEM (Fig. 2) than those of control. The higher shortening level used in this study may be masking the strengthening effects of the surface-active agents on extensigraph properties.

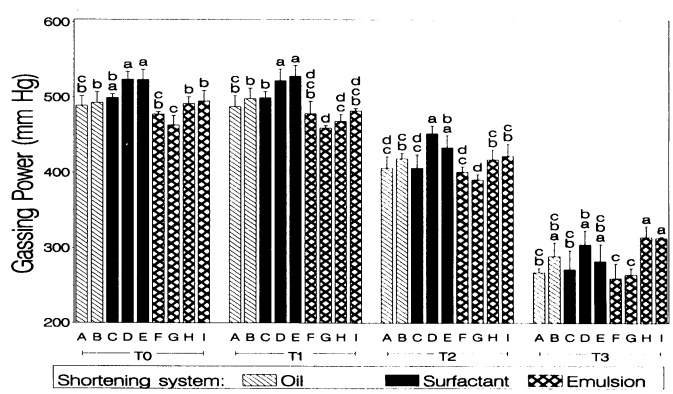

Fig. 3. Effect of shortening system grouped by frozen dough storage period on gassing power. Identity of bars and abbreviations as in Fig. 1.

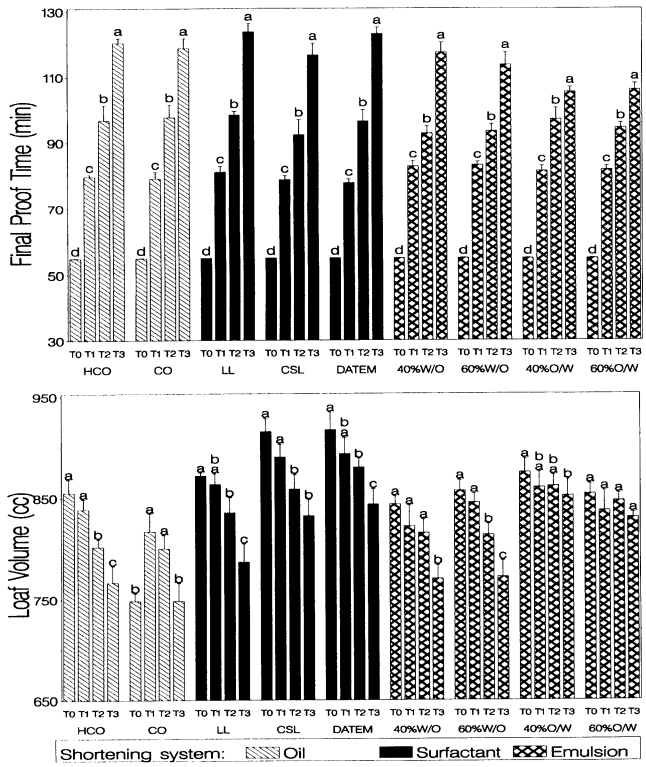

Fig. 4. Effect of frozen dough storage period grouped by shortening system on final proof time and loaf volume. T0 = nonfrozen, T1 = frozen for one day, T2 = frozen for four weeks, T3 = frozen for 10 weeks. HCO = hydrogenated canola oil (control), CO = canola oil, LL = lysolecithin, CSL = calcium stearoyl-2-lactylate, DATEM = diacetyl tartaric acid esters of monoglyceride, 40% W/O = water in oil emulsion (40% water + 60% control), 60% W/O = water in oil emulsion (60% water + 40% control), 40% O/W = oil in water emulsion (40% control + 60% water), 60% O/W = oil in water emulsion (60% control + 40% water). Within each shortening system group, histogram bars annotated with the same letter denote mean values that are not significantly different ($P < 0.05$).

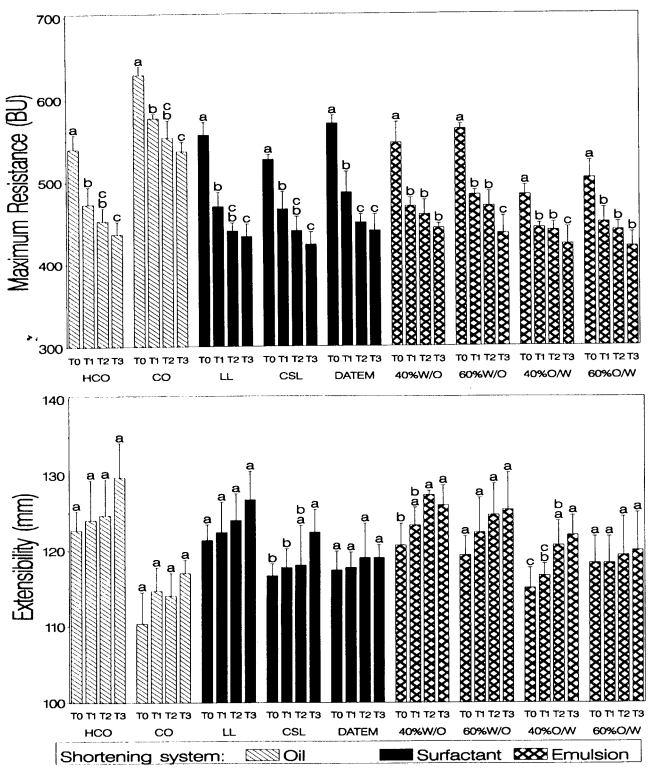

Fig. 5. Effect of frozen dough storage period grouped by shortening system on extensigraph maximum resistance and extensibility. Identity of bars and abbreviations as in Fig. 4.

The nonfrozen doughs with CSL and DATEM gave a significantly higher ($P < 0.05$) gassing power than those from control (Fig. 3). A similar finding was reported by Tsen and Weber (1981). The higher gassing power may be partially responsible for the higher loaf volume. The significant improvement in loaf volume and gassing power produced by the addition of CSL or DATEM was maintained throughout the storage period (Figs. 1–3). However both baking parameters decreased during the extended storage period in a similar manner as those of the control (Figs. 4 and 6). The final proof time of the CSL treatment after 10 weeks of freezing was significantly ($P < 0.05$) lower than that of either the LL or DATEM (Fig. 1) treatments. Otherwise, there were no significant effects of the addition of the surface-active agents on final proof time throughout the storage period. The extensigraph properties of the doughs with the surface-active agents changed with time of frozen storage in a manner similar to those of the control (Fig. 5). These results suggest that the two surface-active agents, CSL and DATEM, improved the baking properties of nonfrozen doughs but did not improve stability of the doughs during frozen storage. The improving effect of the addition of LL on the baking and rheological parameters examined was small.

Type of Emulsion and Amount of Water Incorporated

The movement of water in dough during freezing, frozen storage, and thawing is presumed to cause significant damage in the dough structure (Varriano-Marston et al 1980, Berglund et al 1991, Inoue and Bushuk 1991). The incorporation of part of the dough water in the shortening system may limit the movement of water and thereby improve the ability of the dough to maintain its structure during freezing and storage. To test this hypothesis, the effects of two types of emulsion systems, W/O and O/W, which contained 40 or 60% of water (shortening basis), were investigated.

The W/O emulsion systems had no improving effect on the baking (Fig. 1) and rheological properties of doughs (Fig. 2) during the storage period investigated. On the other hand, considerable

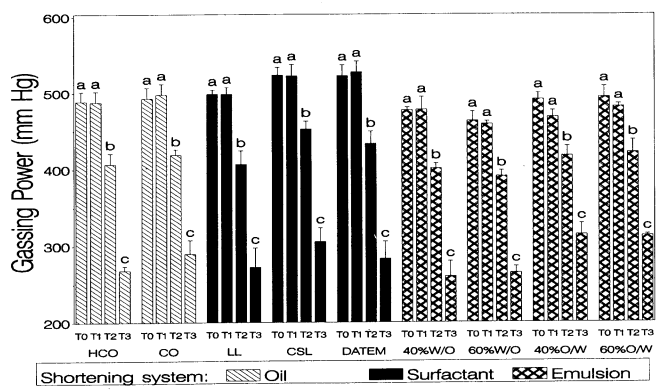

Fig. 6. Effect of frozen dough storage period grouped by shortening system on gassing power. Identity of bars and abbreviations as in Fig. 4.

TABLE I
Standard Proof Height of Doughs Formulated with Different Shortening Systems

Shortening Treatment	Standard Proof Height (mm)[a]
Control	101.3 ± 0.6 a
Canola oil	102.0 ± 0 a
Lysolecithin	102.0 ± 0 a
Calcium stearoyl-2-lactylate	104.0 ± 0 b
Diacetyl tartaric acid esters of monoglyceride	103.3 ± 0.6 b
40% water in oil emulsion	101.6 ± 0.6 a
60% water in oil emulsion	101.3 ± 0.6 a
40% oil in water emulsion	101.6 ± 0.6 a
60% oil in water emulsion	102.0 ± 0 a

[a] Means with the same letter are not significantly different ($P < 0.05$).

TABLE II
Effects of Polyglycerin Monostearate (PGMS) in Oil in Water (O/W) Emulsions or Control Formulations on Extensigraph Properties of Nonfrozen Dough

Treatment	Maximum Resistance[a] (BU)	Extensibility[a] (mm)
Control[b]	540 ± 17 a	123 ± 3 ab
60% O/W[c]	503 ± 21 b	118 ± 4 bc
HCO (9.75%) + PGMS (0.25%)[d]	533 ± 15 a	124 ± 4 a
40% O/W[e]	483 ± 12 c	115 ± 3 c
HCO (9.50%) + PGMS (0.50%)[f]	526 ± 21 a	120 ± 1 a–c

[a]Mean and standard deviation of three replicates. Means in columns with the same letter are not significantly different ($P < 0.05$).
[b]Dough containing 10% (flour basis) hydrogenated canola oil (HCO).
[c]Dough containing 9.75% HCO and 0.25% polyglycerin monostearate (PGMS) (both on flour basis) added as O/W emulsion with 40% water (emulsion basis).
[d]Dough containing 9.75% HCO and 0.25% PGMS (both on flour basis) which were added separately.
[e]Dough containing 9.50% HCO and 0.50% PGMS (both on flour basis) added as O/W emulsion with 60% water (emulsion basis).
[f]Dough containing 9.50% HCO and 0.50% PGMS (both on flour basis) which were added separately.

positive effects of the O/W emulsion systems were observed, particularly for the extended frozen storage treatments. For nonfrozen doughs, loaf volumes (Fig. 1) and gassing power (Fig. 3) of the doughs containing the O/W systems were not significantly different compared to those of the control; although loaf volumes for the 40% O/W emulsion doughs were significantly higher than the 40% W/O emulsion system. However, maximum extensigraph resistance of both the 40 and 60% O/W emulsion nonfrozen doughs were significantly lower than those of the control (Fig. 2). Extensibility of the 40% O/W nonfrozen doughs was significantly lower as well. The change in extensibility for the 60% O/W doughs with extended storage was significantly smaller when compared to the control, particularly between the four-week and 10-week period of frozen storage.

As mentioned above, the noteworthy effects of the O/W emulsion systems were manifested with extended storage. For example, the CSL and DATEM formulae resulted in significantly higher loaf volumes for the nonfrozen and one-day frozen dough treatments. However, there was no significant difference between these surfactants and the 40% O/W emulsion systems after four weeks of frozen dough storage (Fig. 1). DATEM was higher in LV than the 60% O/W treatment only. Comparing all shortening systems after 10 weeks of frozen storage, the O/W emulsion systems were associated with the lowest final proof times and highest loaf volumes (Fig. 1); gassing power was comparable to the CSL and DATEM treatments (Fig. 3). Most notable was the observation that, for the O/W emulsion treatments, the loaf volumes hardly decreased due to the extended frozen storage period (Fig. 4).

The improved baking performance of the frozen doughs containing the O/W systems is probably a result of a modification of the dough structure, making it different from the effects of CSL and DATEM, which did not show a comparable stability of loaf volume (Fig. 4). It should be noted however, that in the preparation of the O/W systems, a hydrophilic surface-active agent, PGMS with HLB of 13, was used. Hosomi et al (1992) showed that a hydrophilic sugar ester with HLB of 15 improved baking and rheological properties of frozen doughs. The PGMS might have directly improved the baking and rheological properties of the frozen doughs containing the O/W emulsion systems examined in this study. However, direct addition of either 0.25 or 0.50% PGMS (flour basis) to the control nonfrozen dough formulation did not cause any significant change in extensigraph properties. This was contrary to the effects of the O/W emulsion treatments (Table II). Accordingly, the modification of the dough structure due the addition of the O/W systems, at least in nonfrozen dough, appears to be caused by the emulsion system, not by PGMS itself.

While the exact mechanism of the modification of dough structure by the O/W systems remains to be elucidated, it seems reasonable to assume that the physical nature of the emulsion would be one of the main contributing factors. In this system, hydrogenated canola oil is emulsified as small droplets or micelles in the water phase of the emulsion. Accordingly, the O/W emulsion system, possibly due to smaller average particle size, may be able to distribute the oil more thoroughly in the dough through the water phase, compared to the other shortening systems investigated, and thus impart greater stability against long-term frozen storage. It was concluded from these results, that properly formulated shortening systems can be used to maintain the quality of bread from frozen doughs during frozen storage.

ACKNOWLEDGMENT

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arabinose. Bengtsson and coworkers (Bengtsson and Åman 1990, Bengtsson et al 1992a) performed methylation analysis on rye water-soluble arabinoxylan fractions. The authors did not detect 2-monosubstituted xylose residues in a fraction comparable to the AX50 fraction of this report. Neither did they detect such units during enzymatic hydrolysis of rye water-soluble arabinoxylans in oligomers or in a polymeric residue rich in disubstituted xyloses (as in AX100). Ebringerová et al (1990) investigated alkali-extractable rye bran arabinoxylans and mentioned the presence of 2-monosubstituted xylose (4%).

With ^{1}H-NMR analysis, the ratio of monosubstituted to disubstituted xylose residues can be determined if the proportion of 2-monosubstituted xylose residues can be neglected. Indeed, due to its ^{1}H-NMR resonance (Ebringerová et al 1990, Viëtor et al 1994), the detection of 2-monosubstituted xylose is hindered by the presence of disubstituted xylose residues. No ^{13}C-NMR spectral data of 2-monosubstituted xylose were available. With methylation analysis, the partially methylated compounds originating from 3- and 2-monosubstituted xylose coelute. However, their detection and quantification can be achieved using GC-MS as described by Gruppen et al (1992a).

The present data show that, next to variation in the proportions of 3-monosubstituted and disubstituted xylose residues, rye water-soluble arabinoxylans also strongly vary in the level of 2-monosubstituted xylose residues. In one fraction, we found 14% 2-monosubstituted xylose residues, which contradicts earlier suggestions about the (virtual) absence of 2-monosubstituted xylose residues in rye water-soluble arabinoxylans (Aspinall and Sturgeon 1957; Bengtsson and Åman 1990; Bengtsson et al 1992a,b; Vinkx et al 1993). With the increased use of enzymes to degrade rye arabinoxylans in both bakery and animal feed applications, the presence of 2-monosubstituted xylose may be of growing importance. Recently, Viëtor et al (1994) showed that in barley arabinoxylans, the presence of 2-monosubstituted xylose blocks the action of endoxylanase I to the same extent as disubstituted xylose and not to the limited extent as found for 3-monosubstituted xylose (Kormelink et al 1993).

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