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Effects of emulsifiers on farinograph and extensograph measurements

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The effects of four different emulsifiers (distilled monoglycerides (MG), diglycerides (DG), diacetyl tartaric acid ester of monoglycerides (DATEM) and lecithin) on the rheological properties of Norwegian wheat flour dough were investigated. A response surface model was used to determine the effects of two independent variables: emulsifier concentration (0–2%) and water addition (55–61%). Dough properties measured were dough development time, maximum consistency and dough stability using a Brabender farinograph, and extensibility and resistance to deformation using a Brabender extensograph. The presence of emulsifier did not influence the dough development time. Maximum consistency and stability were not influenced by MG, whereas DATEM increased the maximum consistency and DG decreased the maximum consistency with increasing concentration. Lecithin decreased the dough stability, particularly at high concentrations. The extensogram characteristics were only influenced by DATEM. DATEM increased the ratio between resistance to deformation and extensibility, which indicates very good dough strengthening properties. Increased water addition generally decreased the maximum consistency and increased the extensibility.

INTRODUCTION

Emulsifiers are commonly added to commercial bread products to improve bread quality and dough handling characteristics. Some frequently used emulsifiers are diacetyl tartaric acid esters of monoglycerides (DATEM) and lecithin, which are known to act as dough improvers, and monoglycerides (MG) and diglycerides (DG), which are used as antistaling agents or 'crumb softeners' (Aust & Doerry, 1992). Rheological instruments are commonly used to determine the dough behaviour and bread quality (Bloksma & Bushuk, 1988). Thus, knowledge about the effect of these emulsifiers on the rheological properties of dough is important.

Dough rheological properties may be measured by several different instruments, including farinograph, extensograph, mixograph, alveograph, and maturograph. Studies of the influence of emulsifiers on rheological properties are so far inconclusive. Tamstorf (1975) reported farinogram characteristics such as dough development time and dough stability to be unaffected by DATEM, calcium stearoyl-2-lactylate (CSL) and MG. Tsen & Weber (1981), however, reported an increased stability by DATEM, sodium stearoyl-2-lactylate (SSL) and CSL. Hydroxylated phosphatides have been reported by Pomeranz *et al.* (1968) to increase the farinogram dough development time.

Studies on the effect of added lipids on extensogram characteristics are not frequently reported. Munz & Brabender (1940), however, found that addition of lecithin (1%) increased the resistance and reduced the extensibility, while the opposite effect was indicated for MG (Horubalowa *et al.*, 1975). Addition of fats (triglycerides) to flour tended to decrease both resistance and extensibility (Merritt & Bailey, 1945).

The main objective of this work was to study the changes in farinogram and extensogram characteristics of strong bread flour by addition of different commercial emulsifiers. Investigations into the effects of various levels of emulsifiers and water additions were included in the study.

MATERIALS AND METHODS

Materials

A commercial Norwegian bread flour (13.0% protein (N×5.7), 0.68% ash) was used (Møllesentralen, Oslo). Distilled monoglycerides (MG), diglycerides (DG) and

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diacetyl tartaric acid esters of monoglycerides (DATEM) were obtained from Grindsted Products (Brabrand, Denmark). MG and DATEM were powdered standard products, with the trade names DIMODAN PV and PANODAN 90, containing about 95% MG and 90% DATEM, respectively. PANODAN 90 also included 10% tricalcium phosphate as an anticaking agent. DG was a laboratory sample of firm consistency, containing 67% DG and 12% MG. Lecithin (soya lecithin) was provided by Denofa og Lilleborg Fabriker, Norway. The emulsifier concentrations (0–2% flour weight basis) were chosen to cover the legal application range for bread in Norway (maximum legal dosage is 20 g kg^{-1} flour for MG and DG, 6 g kg^{-1} flour for DATEM and 10 g kg^{-1} flour for lecithin).

Farinograph measurements

The dough mixing properties were investigated by Brabender farinograph (Brabender, Duisburg, Germany) according to the ISO 5530-1 method (ISO, 1988*a*), with the following modifications: (1) the running time of the farinograph was 5 min; (2) five water addition levels were used instead of adjusting the water addition to the 500 Brabender unit (BU) line. The water addition levels were between 55.0% and 61.0% flour weight basis (Table 1) as this is within a range where good dough handling was possible. The emulsifiers were added directly to the flour and blended in the farinograph to a uniform mix (for 1 min) before the water was added. Dough development time, maximum consistency and dough stability were recorded manually (ISO, 1988*a*). Dough development time was defined as the time in minutes measured from the addition of water to the point on the curve immediately before the first sign of decrease in consistency. The maximum consistency was defined as the consistency in BU, measured at the development time and in the middle of the curve band width, while the dough stability was defined as the drop of the curve (BU) during the first 2 min after dough development time.

Extensograph measurements

Doughs from the farionograph measurements were cut into two parts of 150 g each and passed through the balling and moulder unit of a Brabender extensograph (Brabender, Duisburg, Germany). After 45 min resting in the fermentation cabinet, the dough was stretched. After this first test, the balling and moulding operations were repeated and the doughs were tested again after a further 45 min resting time. The same procedure was repeated for a third time, following the ISO 5530-2 method (ISO, 1988*b*). The results were expressed as the resistance to constant deformation after 50 mm stretching (R_{50}), the extensibility (E), described as the distance travelled by the recorder paper from the moment that the hook touches the test piece until rupture of the test piece, and the ratio between the two of them (R_{50}/E).

Table 1. Water addition levels and emulsifier concentrations for the response surface model

Experiment no.	Water addition (%)	Emulsifier concentration (%)
1	55.0	1.0
2	55.9	0.3
3	55.9	1.7
4	58.0	0
5	58.0	1.0
6	58.0	1.0
7	58.0	1.0
8	58.0	2.0
9	60.1	0.3
10	60.1	1.7
11	61.0	1.0

Experimental design and statistical analysis

For this study a response surface method was used (Montgomery, 1984). An approximately central composite design, based on 11 trials, with three replicates at the centre point, was chosen to study the effects of two independent variables: water addition and emulsifier concentration. The experiments were conducted according to Table 1, to explore the response surface over the defined area. The results are shown as quadratically smoothed surfaces. Most plots are two-dimensional projections (smoothed contour plots), while three-dimensional plots are presented for R_{50}/E. All the measured variables were analysed by a three-way ANOVA model, with emulsifier type, emulsifier dosage and water addition as fixed effects ($P < 0.05$). The results for extensibility after 135 min total resting time were analysed by a separate Tukey's test for multiple comparisons for each emulsifier.

RESULTS

Effects of various additions of water and emulsifiers on farinograph measurements

The effects of water and emulsifiers on the farinogram maximum consistency are shown in the smoothed contour plots in Fig. 1. Maximum consistency generally decreases by increasing the water addition from 55% to 61% (Fig. 1(a)–(d)). Without emulsifier, the normal water addition in a farinograph, corresponding to a maximum consistency of 500 BU, was found to be an average of 58.2%.

As shown in Fig. 1(a), MG did not significantly affect the maximum consistency in doughs with low water additions. In high water doughs, maximum consistency increased slightly up to 1% MG but decreased slowly from 1% to 2% (Fig. 1(a)). For DG (Fig. 1(b)) the maximum consistencies were found to decrease with increasing concentration at all water levels. At 56% water, addition of 2% DG reduced the maximum consistency from about 600 to 490 BU, while at 60% water addition the reduction was from 450 BU to about 380 BU. Increased concentration of DATEM increased the maximum consistency (Fig. 1(c)), with the greatest effect (about 50 BU) at 1–1.5% DATEM. Lecithin (Fig. 1(d)) showed a minor increase in the maximum consistency at high concentrations and high water addition and a minor decrease at low water levels.

The development times for doughs without emulsifiers were between 2 and 2.5 min (results not shown). The dough development times were not significantly affected either by increasing the emulsifier dosage from 0% to 2% or by increasing the water addition level from 55% to 61%.

The dough stability, measured during the first 2 min after development time, is illustrated by the farinograms in Fig. 2. A distinct reduction in dough stability was found for lecithin compared to doughs without emulsifiers. The effect increased by increasing concentrations, resulting in a drop of around 50 BU after addition of 2% lecithin (Fig. 2). Only minor reductions (at most 20 BU) were found in doughs with MG or DG, while the stability of doughs with added DATEM tended to increase by increasing concentrations.

Effects of various water additions and emulsifiers on extensograph measurements

The effects of various water additions and emulsifiers on the extensograph extensibility after 135 min total resting time are shown in the smoothed contour plots in Fig. 3. All emulsifiers increased the extensibility by increasing water addition up to about 59% (Fig. 3(a)–(d)). Lecithin and DATEM continued to increase above 59% added water, while quite stable levels were achieved for MG and DATEM. Addition of MG did not significantly affect the extensibility after 135 min total resting time (Table 2 and Fig. 3(a)), whereas increasing levels of DATEM decreased the extensibility significantly (Fig. 3(c) and Table 2). The effects of DG and lecithin on extensibility were more complex. Both DG and lecithin increased extensibility at low water additions (Fig. 3(b) and (d)), but the average effect for all water additions was not significant (Table 2).

The resistance to constant deformation (R_{50}) increased between the fermentation stages, with the greatest increase

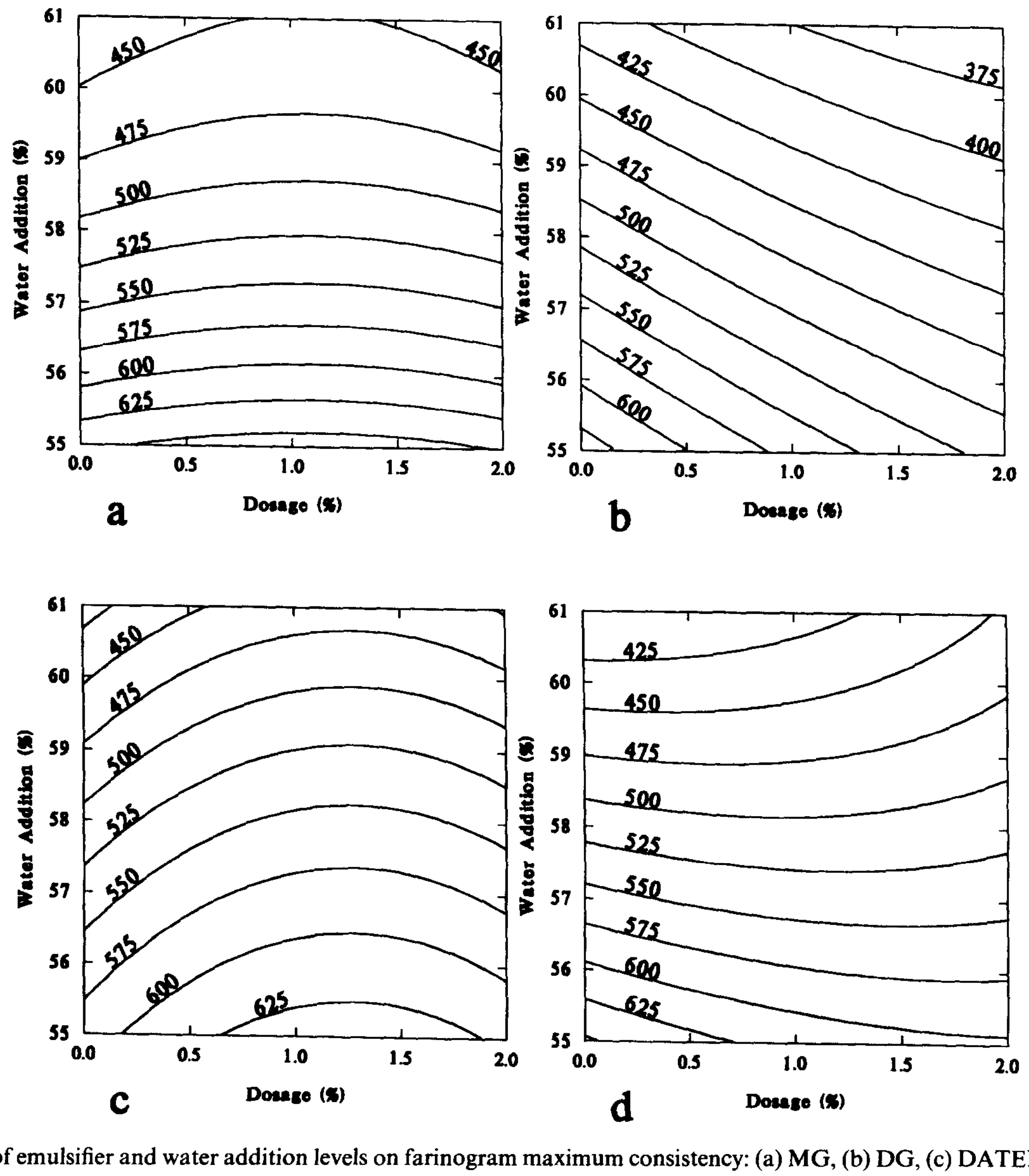

Fig. 1. Effect of emulsifier and water addition levels on farinogram maximum consistency: (a) MG, (b) DG, (c) DATEM, (d) lecithin.

between 45 and 90 min (Table 3). The resistance decreased by about 20% as the water addition increased from 55% to 61%. Addition of MG, DG and lecithin affected R_{50} only slightly (maximum change of 80 BU from 0% to 2% emulsifier). The level of R_{50} was, however, found by Tukey's test to be significantly lower for lecithin than for MG, after both 90 and 135 min (Table 3). The resistance of doughs with added DATEM was significantly higher (180–300 BU) than for the other emulsifiers. The effect was greatly affected by dosage: for example, 2% DATEM increased R_{50} by 400–500 BU (results not shown).

The increased R_{50} (Table 3) and decreased extensibility (Table 2) for DATEM resulted in an increased R_{50}/E ratio, as is shown in the three-dimensional plots of the R_{50}/E ratio after 135 min total resting time (Fig. 4). MG, DG and lecithin did not increase the R_{50}/E ratio. Increased water addition generally reduced both resistance (Table 3) and extensibility (Fig. 3), resulting in an almost constant R_{50}/E ratio for MG, DG and lecithin (Fig. 4). The effect of DATEM on the R_{50}/E ratio, however, decreased by increasing water addition.

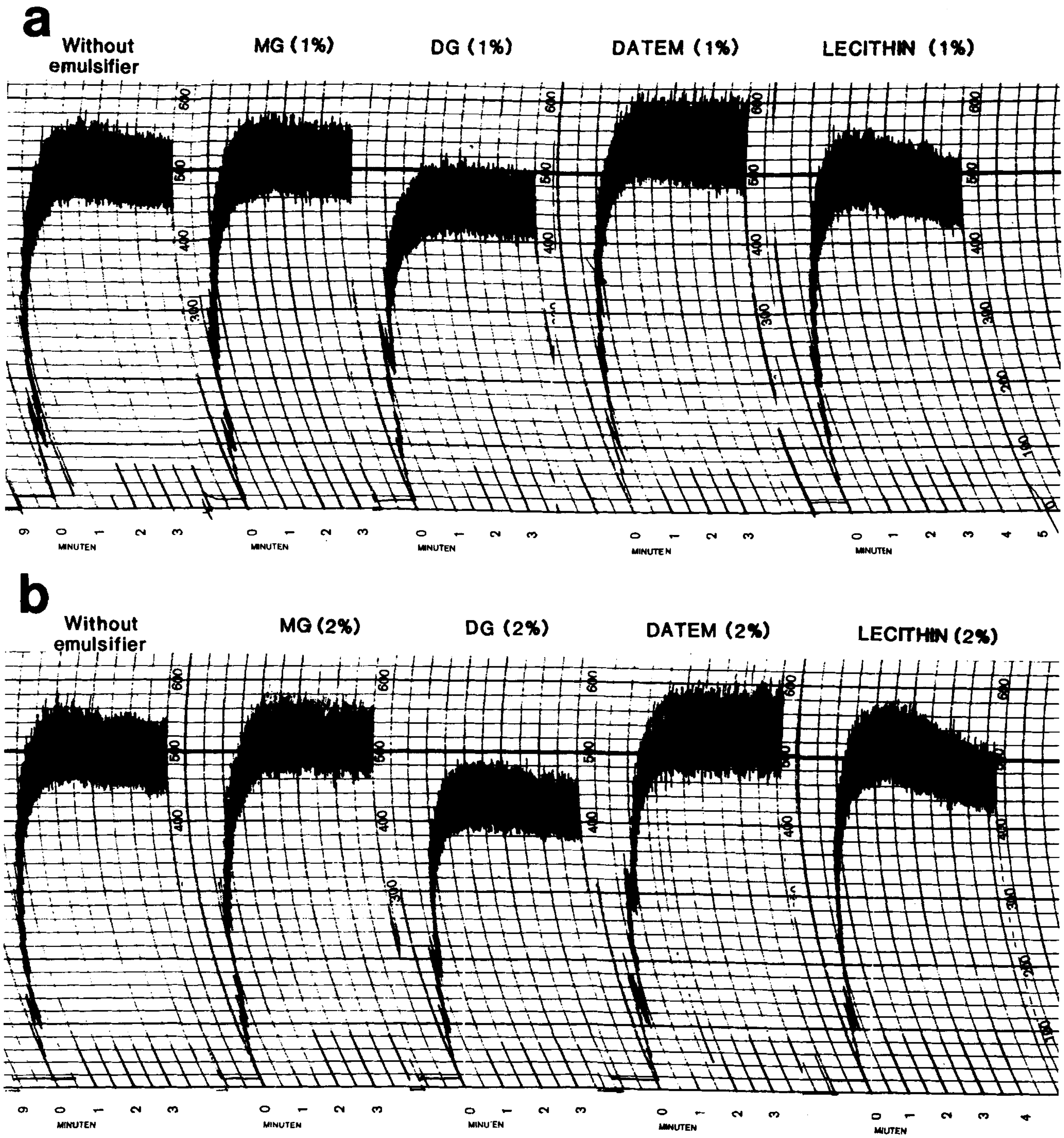

Fig. 2. Effect of concentrations of the emulsifiers MG, DG, DATEM and lecithin on farinogram characteristics with constant water addition (58%), and (a) 1% and (b) 2% emulsifier dosage.

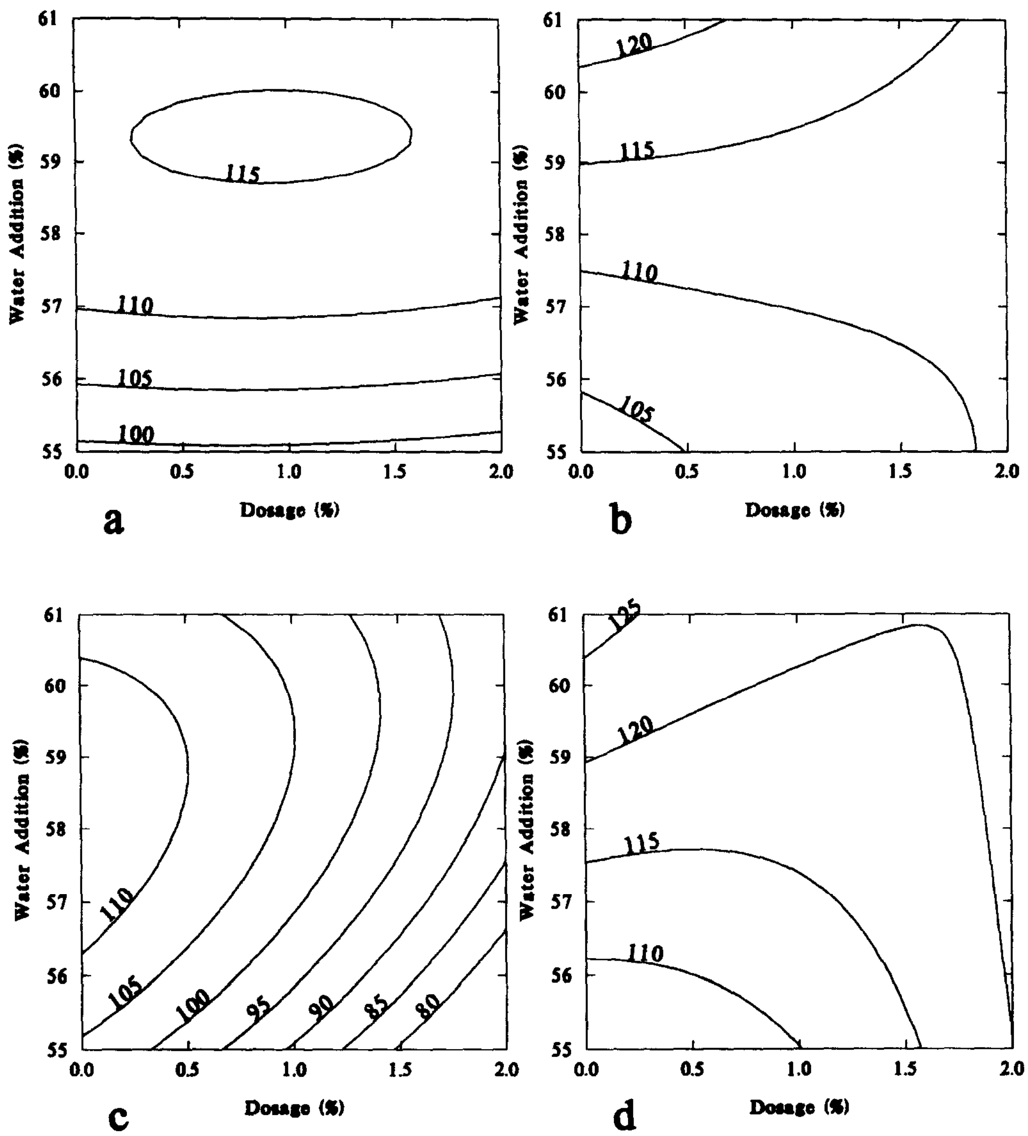

Fig. 3. Effect of emulsifiers and water addition levels on extensogram extensibility of the dough after 135 min total resting time: (a) MG, (b) DG, (c) DATEM, (d) lecithin.

DISCUSSION

Among the four emulsifiers investigated, DATEM was the only emulsifier with major influences on both farinogram and extensogram characteristics. Extensogram characteristics are particularly useful in prediction of the dough's strength (Brabender, 1958). Increased resistance to deformation (R_{50}) predicts good dough handling properties and a large fermentation tolerance, especially during final proof (Brabender, 1958). The R_{50}/E ratio has been found to be an indicator of baking performance (Brabender, 1958). In our study DATEM increased both R_{50} and the R_{50}/E ratio. Thus the good dough strengthening and baking quality improving effect of DATEM described by Mettler *et al.* (1991) was confirmed. The dough strengthening effect of DATEM has been related to strong binding effects and thereby to the promotion of the development of a gluten–starch–lipid complex (Mettler *et al.*, 1991).

DATEM was also found to increase the farinogram maximum consistency. This increase may be explained by increased water absorption (Fig. 1). Increased water absorption by dough strengtheners has previously been reported by Langhans & Thalheimer (1971) and by Tamstorf *et al.* (1986). In the present study, farinogram development time and stability were not significantly affected by addition of DATEM. This is in agreement

Table 2. Extensibility after 135 min total resting time for emulsifiers with different dosages, given as the average for water additions

	Emulsifier			
Emulsifier dosage (%)	MG	DG	DATEM	Lecithin
0	117.0	115.0	111.5[a]	118.0
0.3	106.8	109.0	109.3[a]	114.8
1.0	111.3	113.6	100.2[b]	115.9
1.7	110.0	109.0	89.0[c]	119.5
2.0	111.5	114.0	87.0[c]	119.5

Means with the same letter within one emulsifier are not significantly different ($P < 0.05$). No significant differences are found for MG, DG and lecithin.

with Tamstorf (1975), who found no significant changes in farinogram development times or stability when using either MG or DATEM.

Table 3. Resistance to constant deformation (R_{50}) by extensograph after different resting times

	Resting time		
	45 min	90 min	135 min
Emulsifier			
MG	336^b (36)	477^b (34)	521^b (53)
DG	343^b (40)	470^b (40)	505^{bc} (46)
DATEM	510^a (134)	751^a (191)	752^a (162)
Lecithin	331^b (33)	446^c (46)	489^c (45)
Water addition			
55.0%	435^a (68)	606^a (162)	651^a (173)
55.9%	417^a (126)	577^a (201)	563^b (51)
58.0%	378^b (109)	529^b (149)	571^b (151)
60.1%	338^c (86)	481^c (150)	511^c (137)
61.0%	342^c (54)	490^c (81)	531^c (94)

Means (standard deviation) for the effects of emulsifier, respectively water addition, are given as the average for all other variables.
Means with the same letter within one variable and one resting time are not significantly different ($P < 0.05$).

The doughs with added lecithin appeared to be dry and smooth (determined by handling of the dough). Previously, dryer doughs and improved handling properties of doughs with added lecithin have been reported by Inakumara *et al.* (1989), and are suggested to be due to increased water absorption. In this study, the good dough handling properties were not reflected in increased water addition or other measured dough characteristics. The extensograph measurement for R_{50} after 90 and 135 min was lowest for lecithin (Table 3), while extensibility increased at low water levels (Fig. 3). In conjunction with a reduced farinogram dough stability, this indicated a minor weakening effect of lecithin, entailing that the dough will withstand less mechanical abuse (D'Appolonia, 1990). This is in contrast to the dough strengthening effect reported by Rotsch (1967), and the increased R_{50}/E ratio found by Munz & Brabender (1940). The expected dough strengthening effect of lecithin is suggested to be caused by displacement of the flour lipid binding by lecithin binding in the dough system (Mettler *et al.*, 1991). As phospholipids have smaller effects on the baking properties than the polar galactolipids, higher concentrations of lecithin are probably needed to restore good baking properties. The concentration of effective phospholipids in the crude

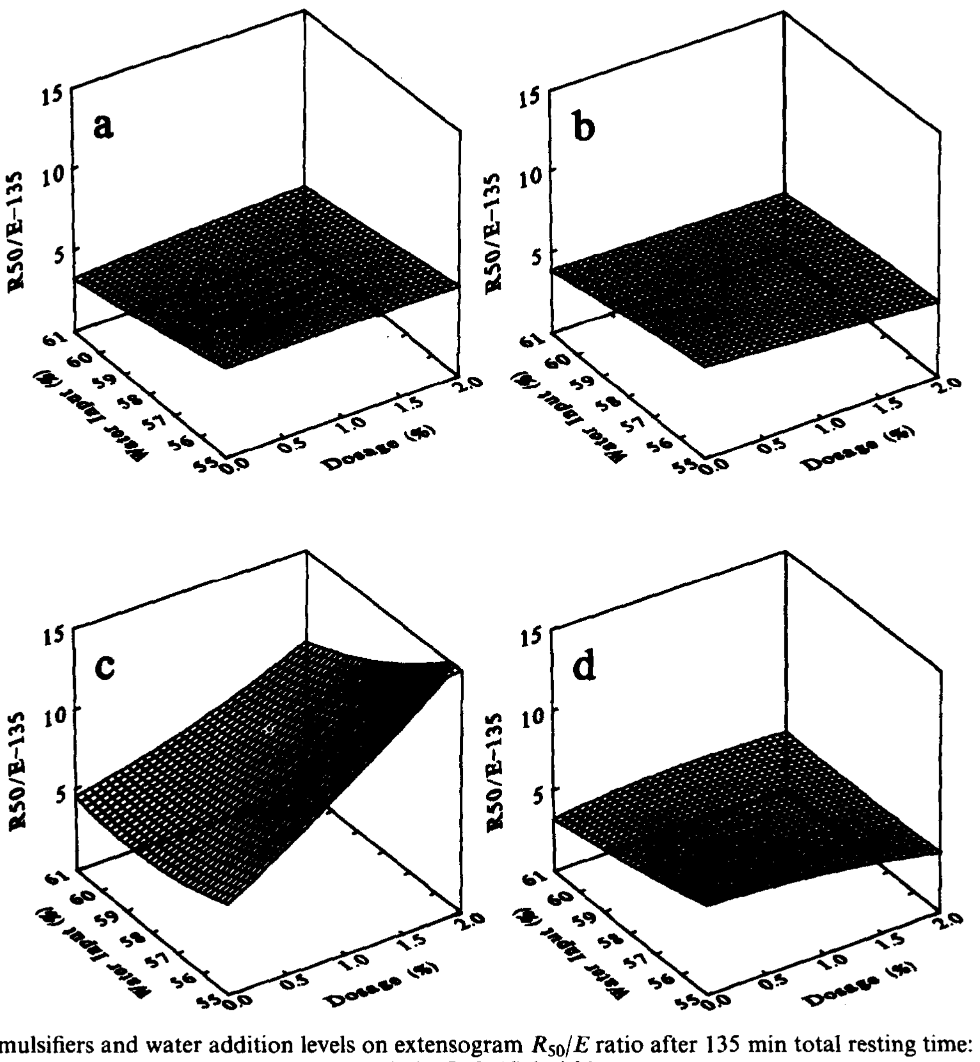

Fig. 4. Effect of emulsifiers and water addition levels on extensogram R_{50}/E ratio after 135 min total resting time: (a) MG, (b) DG, (c) DATEM, (d) lecithin.

soya-lecithin used in this experiment may thus have been too low to give an improving effect.

MG and DG had only minor effects on the extensogram characteristics (Fig. 4), and are thus not expected to have dough strengthening effects or to improve the baking performance. MG and DG are primarily used for their ability to react with the starch and delay staling, and are only found to undergo weak bindings in the dough system (Mettler *et al.*, 1991). In previous studies an increased extensibility for MG (Horubalowa *et al.*, 1975) has even been reported, indicating a weakening effect of this emulsifier. The reduction in maximum consistency for the DG sample, which also contained some MG, is probably related to a reduced water absorption, as illustrated in Fig. 2. A similar effect, with reduction of the maximum consistency, has been reported previously after addition of fat (Langhans & Thalheimer, 1971).

In addition to variations caused by DATEM, the main variations in farinogram and extensogram characteristics were caused by differences in water addition. Farinogram maximum consistency was greatly influenced by water addition. Below the normal water addition of 58.2% found for flour without emulsifier, the dough remained dry and stiff and showed high maximum consistency. Above 58.2% water addition, the water absorption capacity of the flour was exceeded and the amount of free water increased and smoothed the dough, resulting in lower maximum consistency in the farinograms.

The development time was not influenced by water addition within the chosen 55–61%, which represented the range for good dough handling. With a wider range, increasing water additions would be expected to increase the development times, as was previously found in experiments with 58–70% water in a 35 g mixograph (Lang *et al.*, 1992) and 54–68% water in a 125 g mechanical dough development mixer (Larsen & Greenwood, 1991).

CONCLUSIONS

The results from the farinograms and extensograms showed that MG, DG and lecithin only slightly influenced the measured dough properties, especially when used in low concentrations. For MG, which is an emulsifier with low dough strengthening ability, neither the extensograms nor the farinograms demonstrated significant changes in the dough properties, confirming that MG probably does not bind strongly to the gluten strands in the dough system. Lecithin reduced the dough stability in the farinograph, which indicates a weakening effect on the dough. DG decreased the maximum consistency. This is similar to effects reported when adding fat. DATEM increased the water absorption of the dough (measured as an increase in maximum consistency) and strengthened the dough by improving the resistance to deformation as well as the R_{50}/E ratio. As improving effects of DATEM on baking quality have been previously found by other investigators, farinograph and extensograph characteristics as used in this study may prove useful in prediction of baking quality.

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