Effects of Emulsifiers and Hydrocolloids on Whole Wheat Bread Quality: A Response Surface Methodology Study[1]

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Cereal Chem. 70(4):373–377

ABSTRACT

The effects of monodiglyceride (MDG), diacetyl tartaric ester of monoglycerides (DATEM), guar gum (GG), and carboxymethylcellulose (CMC) on the rheological properties of whole wheat flour dough and the functional properties of the final product were investigated. A response surface model was used to evaluate the effects observed and to determine the optimum formulation for whole wheat bread. The study included 44 combinations of the following independent variables: MDG (0.0–0.6 parts), DATEM (0.0–0.6 parts), GG (0.0–1.0 parts), and CMC (0.0–1.0 parts). Dough properties measured for each combination formulation were final proof time, fermentation stability, dough elasticity, and dough height. The oven rise was followed during the baking process. Bread quality attributes determined were specific volume, crumb grain, crumb elasticity, and increase in crumb firmness during storage. Whole wheat bread with a high volume, good crumb grain, and excellent shelf life was produced using 0.3 parts MDG, 0.6 parts DATEM, 0.15 parts GG, and 0.6 parts CMC. The results suggest that emulsifiers and hydrocolloids can be combined in a baking improver, contributing to optimum functional properties of whole wheat bread.

The effects of emulsifiers and hydrocolloids on the functional properties of wheat bread have been investigated (Lagendijk and Pennings 1970, Joensson and Toernaes 1987, Knightly 1988, Krog et al 1989, Mettler 1990, Mettler et al 1991 a-f). Relationships between the additives used and the rheological properties of dough, as well as the quality attributes of bread, were established. The investigations of Mettler et al (1991 a-f) showed a significant beneficial effect from emulsifiers (diacetyl tartaric ester of monoglycerides [DATEM] and monodiglyceride [MDG]) in the preparation of whole wheat bread. This could be attributed to gluten-lipid interactions during dough preparation and to complexation of the emulsifiers with wheat starch during baking. Among the hydrocolloids examined, guar gum (GG) and carboxymethylcellulose (CMC) showed the most pronounced effects. They caused a significant improvement of the functional properties of wheat bread, especially in combination with DATEM and MDG.

The present study was designed to examine the effects of emulsifiers and hydrocolloids on whole wheat flour dough and whole wheat bread and to determine the optimum formulation for whole wheat bread. Relationships between the additives used and rheological dough properties, as measured with the maturograph and the oven rise recorder, and the quality parameters of whole wheat bread were statistically evaluated. A response surface methodology (RSM) study was done using a fractionated factorial test plan and multipolynomial regression equations. RSM, as described by Box and Wilson (1951), has especially been used in studies of extrusion cooking for product development (Lengerich 1984, Meuser et al 1984, Nestl 1989).

MATERIALS AND METHODS

Materials

A commercial whole wheat flour containing 12.1% (db) protein and 1.38% (db) ash was used. A detailed characterization of the flour is given in Mettler (1990).

The emulsifiers MDG and DATEM were used (Chemische Fabrik Grünau GmbH, Illertissen, Germany). The MDG had a total monoglycerides content of 90–95%. The fatty acid component consisted mainly of stearic and palmitic acids. The fatty acid basis of DATEM was a monoglyceride (Mettler et al 1991a). The emulsifiers were added as a powder. The hydrocolloid GG was supplied by Ulmer Spatz Vertriebsgesellschaft für Backmittel mbH, Neu Ulm, Germany; the CMC was supplied by Kalle AG, Wiesbaden-Biebrich, Germany.

Methods

The preparation of dough and bread followed the pan bread baking test procedure described by Seibel et al 1979. The formula is given in Table I. After dough prefermentation, 150 g of the dough was used for final proof in the maturograph (Brabender oHG, Duisburg, Germany), and 50 g was used in the oven rise recorder (Brabender). The rest of the dough was used for the baking test. The dough was molded, pan-proofed at 32°C and 80% rh for 50 min, and then baked at 210°C for 60 min. All data were duplicated.

Maturograph

The maturograph is an instrument to measure physical dough properties and to determine the optimum final proof time (Seibel and Crommentuyn 1963). Constant conditions (32°C, 80% rh) were maintained in the maturograph measuring cabinet. For recording the fermentation process, the dough was compressed with a force of 0.04 N/(cm^2) by a surface plunger (38 cm^2, 150 g) at 2-min intervals. The dough height or volume was calculated

TABLE I
Whole Wheat Bread Formula

Ingredients	Parts[a]
Constant	
Sour dough (10%)	
Whole wheat flour	10
Starter	0,05
Water	20
Dough	
Sour dough	30 (10 whole wheat/20 water)
Whole wheat flour	90
Salt	1.5
Yeast	1.5
Ascorbic acid	0.01
Water	47.9
Variable	
Emulsifiers	
Monodiglyceride	0.3 and 0.6
Diacetyl tartaric ester	0.3 and 0.6
Hydrocolloids	
Guar gum	0.5 and 1.0
Carboxymethylcellulose	0.5 and 1.0
Additional water	
With guar gum	5.0 and 10.0
With carboxymethylcellulose	3.5 and 7.0

[a]Total quantity = 100 parts.

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from the maximum of the unloaded fermentation curve; dough elasticity was measured from the width of the curve. The optimum final proof time was reached at the maximum for the unloaded fermentation curve. The fermentation stability (min) is related to the optimum final proof time, measured by placing a template into the maximum of the curve; it was determined as the time interval in which the curve was clearly visible in the window of the pattern. A uniform bread volume can be expected within this range (Seibel and Crommentuyn 1963). At optimum final proof time a different dough was placed in the baking oven.

Oven Rise Recorder

The oven rise recorder can be compared with a fryer. It followed the volume increase during baking. The 50-g dough piece was placed into the oil bath of the oven rise recorder. Within 22 min, the oil temperature rose from 30 to 100°C at a heating rate of 3°C/min. The volume increase of the dough caused by heating was recorded by a scaling system and is referred to as oven rise.

Evaluation of Bread Quality

After baking, the bread was stored about 24 hr in polyethylene bags. Sensory evaluation of the bread was performed by three trained panelists. Evaluation criteria were based on those elaborated for the standard baking test of white pan bread (Seibel et al 1979). Crumb grain was assessed on the basis of the dimensionless scoring scheme proposed by Dallmann (1958). This scheme was used for multipolynomial evaluation. Results of the sensory evaluation of crumb elasticity were transformed into quality numbers according to Dallmann (1958) (Table II). These numbers were used for statistical evaluation.

The bread volume was measured by the rapeseed displacement method, and the specific volume calculated as ml/100 g of bread. Crumb firmness was measured with a consistometer (LFRA Texture Analyser, Stevens & Son Ltd, St. Albans, England). This instrument measures the force required to bring a 4-cm^2 spherical probe 5 mm into a sample at a speed of 0.5 mm/sec. According to Morandini and Wassermann (1971) and Maleki and Seibel (1972), the measurements were carried out on both sides of a 5-cm slice taken from the center of the loaf. The measurements were carried out one, two, and three days after baking. A regression line showing the increase in firmness as a function of storage time was obtained. The regression coefficient of this line was used for multipolynomial evaluation.

Experimental Design

An RSM study, as described by Box and Wilson (1951), was conducted of the relative contribution of variables (emulsifiers and hydrocolloids) to dough and bread characteristics and to determine the optimum bread formulation. Combinations of the four independent variables (MDG, DATEM, GG, CMC) were selected. The complete experimental design, four factors at three levels, required $3^4 = 81$ formula combinations. On the basis of a fractional factorial test plan, the number of tests could be reduced to 44 (Table III). Concentration levels of the independent emulsifiers and hydrocolloid variables were calculated using the formulas given in Table IV. Dependent variables showing dough characteristics for each combination were final proof time, fermentation stability, and dough height. Oven rise was included to follow the events during baking. Bread quality attributes measured for each combination were specific volume, crumb grain, crumb elasticity, and increase of crumb firmness during storage.

The data obtained from this study were treated by multiple regression analysis. Nestl (1989) reported that it is not possible to characterize functional relationships sufficiently on the basis of the correlation coefficients (r) determined. Thus, further statistical terms (statistic security [S] and the variance homogeneity [F]) were employed to control the correlations calculated.

The starting concentrations were determined in preliminary baking tests using both normal and extreme concentrations (Mettler 1990). In order to determine the effects of the independent variables on the quality parameters of dough and bread, three-dimensional diagrams and contour plots for each quality parameter were generated as a function of two variables (DATEM and GG), while the other two variables (MDG and CMC) were held constant at the medium level.

The reticulated planes in the three-dimensional diagrams (response surfaces) reflect combinations of additives needed to achieve a response calculated. This is also illustrated by the two-dimensional contour plots. The optimum bread formulation was obtained by superimposing the contour plots.

RESULTS AND DISCUSSION

The relationships between the independent variables (DATEM, MDG, GG, CMC) and the dependent variables were described adequately with sufficient statistical confidence (Table V).

TABLE II
Evaluation of Crumb Elasticity

Crumb Elasticity	Quality Numbers
Good	0
Fairly good	−5
Satisfactory	−10
Unsatisfactory	−75
Very poor	−100

TABLE III
Fractionated Factorial Test Plan[a,b]

		x_1								
		−1			0			1		
x_3	x_4/x_2	−1	0	1	−1	0	1	−1	0	1
−1	−1	x	x	x	x			x		x
	0	x	x	x	x	x		x	x	x
	1	x	x	x	x			x		x
0	−1	x	x	x	x	x		x		
	0		x		x	x	x		x	
	1					x				
1	−1	x	x	x	x			x		x
	0		x			x			x	
	1	x		x				x		x

[a] X_1 = monodiglyceride; X_2 = diacetyl tartaric ester of monoglycerides; X_3 = guar gum; X_4 = carboxymethylcellulose.
[b] −1, 0 and 1 indicate addition levels of additives as given in Table IV.

TABLE IV
Addition Levels of Emulsifiers and Hydrocolloids[a]

Independent Variable	Additive	Addition levels[b] −1	0	1
X_1	Monoglyceride	0	0.3	0.6
X_2	Diacetyl tartaric ester	0	0.3	0.6
X_3	Guar gum	0	0.5	1.0
X_4	Carboxymethylcellulose	0	0.5	1.0

[a] Expressed in parts of 100 parts of flour weight.
[b] See Table III.

TABLE V
Statistical Confidence

	r[a]	S[b] %	F[c]
Final proof time	0.88	100***	6.42***
Fermentation stability	0.88	100***	6.29***
Dough elasticity	0.84	99.97***	4.57***
Dough height	0.92	100***	9.72***
Oven rise	0.93	100***	11.60***
Specific volume	0.94	100***	14.51***
Crumb grain	0.89	100***	7.06***
Crumb elasticity	0.98	100***	41.32***
Crumb firmness	0.90	100***	8.24***

[a] r = correlation coefficients.
[b] S = statistic security.
[c] F = variance homogenity.

Effect of Fermentation Behavior in the Maturograph

Figure 1 shows the effect of GG and DATEM on dough characteristics at constant medium levels of MDG and CMC. Final proof time is one of the most important factors in fully automated breadmaking. Maximum utilization of machinery can tolerate only slight variations, especially in final proof time. Increasing levels of DATEM caused an increase in final proof time (Fig. 1a). In contrast, adding hydrocolloids and MDG decreased final proof time. When DATEM and GG were added in combination, the negative effect of GG was partly reduced. However, the predominating influence of GG caused a general decrease in final proof time (Fig. 1a).

The fermentation stability was especially affected by emulsifiers. The DATEM-induced increase in final proof time led to an increase in fermentation stability. In combination, DATEM and GG caused an increase in fermentation stability (Fig. 1b) that could be attributed mainly to DATEM. This beneficial interactive effect was supported by MDG and CMC (at optimum levels) (Mettler 1990).

Dough elasticity reflects the ability of the dough structure to sustain deformations without rupture and to recover upon removal of stress. DATEM considerably improved dough elasticity, whereas MDG had only a minor effect. Increasing concentrations of CMC resulted in a slight decrease in dough elasticity. This effect was more pronounced when GG was added (Mettler 1990). The detrimental effects of hydrocolloids could be compensated for, in part, by increasing concentrations of DATEM. However, due to the dominating influence of GG, combined additions of DATEM and GG led to a decrease in dough elasticity (Fig. 1c). Because changes in dough elasticity are generally accompanied by corresponding changes in dough height, the effect of additives on dough height (Fig. 1d) are similar to those shown in Figure 1c.

Effect of Baking Performance in the Oven Rise Recorder

The beneficial effect of emulsifiers on the fermentation properties of the dough also led to an increase in oven rise during the baking process (data not shown). DATEM showed the most pronounced effect, followed by MDG. The hydrocolloids, especially when added at the highest level, supported the positive influence of the emulsifiers on the oven rise.

Effect on Whole Wheat Bread Properties

The effect of GG and DATEM on the specific volume is shown in Figure 2. The results are similar to those obtained for the oven rise. Both GG and DATEM caused an increase in specific volume. Isolines show the exact additive combination for a special quality characterization. This is very important for product development.

The crumb grain was only slightly affected by the additives. Whereas emulsifiers appeared to improve crumb grain, hydrocolloids had a slightly detrimental effect (data not shown).

With exception of MDG, all other additives examined reduced the crumb elasticity. GG contributed most to the reduction in elasticity (Fig. 3). This could be related to the high amount of water required for bread preparation in the presence of GG. Also, DATEM was associated with a reduced crumb elasticity, probably because of a thinning of the crumb walls surrounding the air spaces in the high volume bread.

The increase in crumb firmness during storage was reduced by DATEM and hydrocolloids (data not shown). The statistical evaluation of the results indicated that the volume increase is more important for the reduced firmness than the amount of water added during preparation of the dough. Thus, if a reduction in firmness (i.e., freshness) is desired, and the emulsifier used (e.g., MDG) is expected to bring about only a small increase in volume, adding hydrocolloids would be preferred. This was demonstrated by statistical evaluation (Mettler 1990).

Optimum Whole Wheat Bread Formulation

The optimum formulation for whole wheat bread was obtained by superimposing the contour plots of the bread quality parameters specific volume (Fig. 2), crumb grain (not shown), crumb elasticity (Fig. 3), and crumb firmness during storage (not shown)

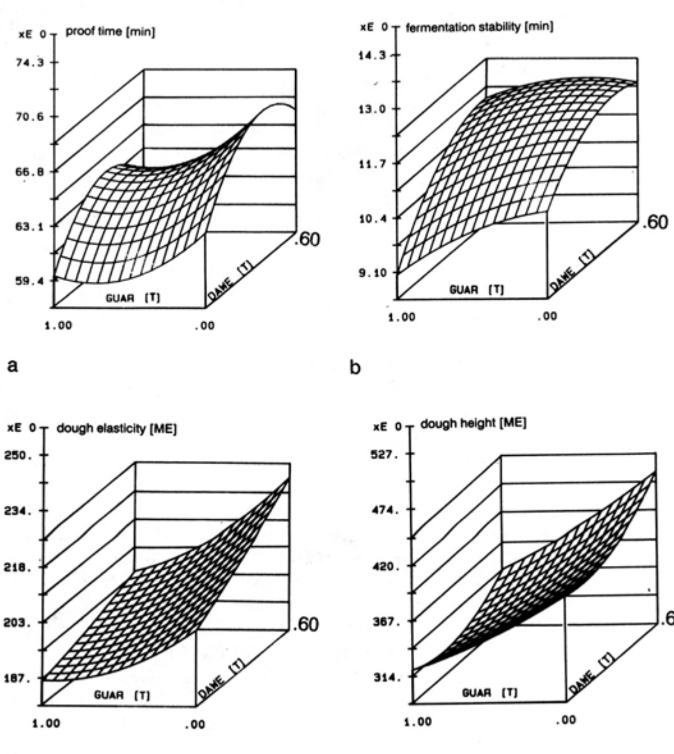

Fig. 1. Effect of guar gum and diacetyl tartaric ester of monoglycerides (DAWE) on final proof time (**a**), fermentation stability (**b**), dough elasticity (**c**), and dough height (**d**) at constant medium levels (monodiglycerides, 0.3 parts and carboxymethylcellulose, 0.5 parts). T = parts.

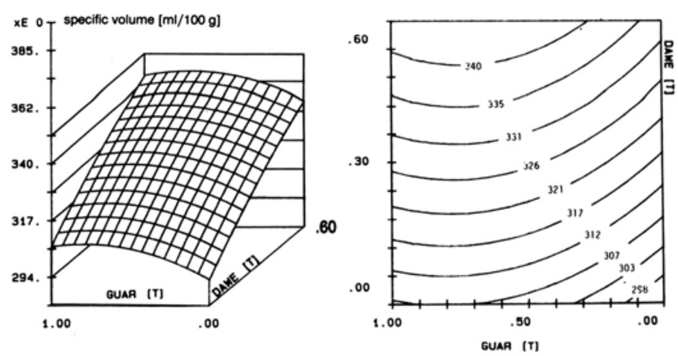

Fig. 2. Effect of guar gum and diacetyl tartaric ester of monoglycerides (DAWE) on specific bread volume at constant medium levels (monodiglycerides, 0.3 parts and carboxymethylcellulose, 0.5 parts). T = parts.

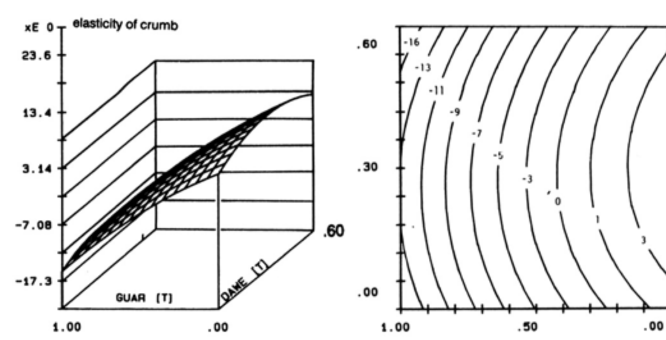

Fig. 3. Effect of guar gum and diacetyl tartaric ester of monoglycerides (DAWE) on crumb elasticity (at constant medium levels of monodiglycerides, 0.3 parts and carboxymethylcellulose, 0.5 parts). T = parts.

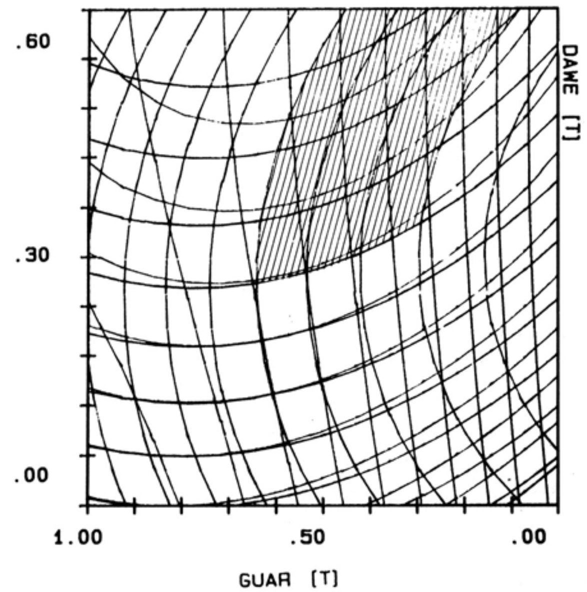

Fig. 4. Determination of the optimum whole wheat bread formulation. The optimum (crosshatched) area indicates required levels of guar gum and diacetyl tartaric ester of monoglycerides (DAWE) on crumb elasticity (at constant medium levels of monodiglycerides, 0.3 parts and carboxymethylcellulose, 0.5 parts). T = parts.

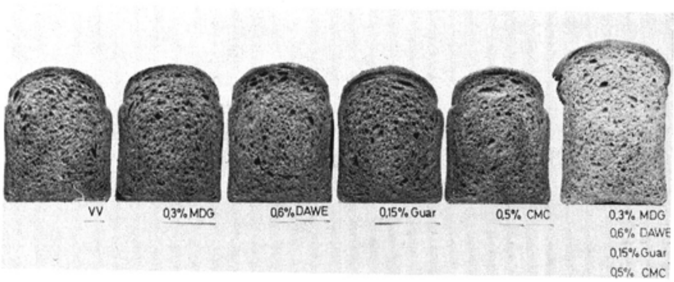

Fig. 5. Application of the optimum formulation in the baking test. VV = control bread, % = parts, MDG = monodiglyceride, DAWE = diacetyl tartaric ester of monoglycerides, Guar = guar gum, CMC = carboxymethylcellulose.

as a function of GG and DATEM. The optimum (crosshatched) area in Figure 4 shows the required additions of GG (0.1–0.5 parts) and DATEM (0.3–0.6 parts) at constant medium levels of MDG (0.3 parts) and CMC (0.5 parts). The result also indicates that variations in the concentrations of GG and DATEM can be tolerated without encountering detrimental effects. The positive effect of medium concentrations of MDG and CMC was found in preliminary tests (Mettler 1990). Therefore the optimizing study was done on the basis of constant additions of MDG and CMC and variable additions of GG and DATEM.

In the baking test, a high-quality whole wheat bread could be produced using the calculated optimum formulation: 0.3 parts MDG, 0.6 parts DATEM, 0.15 parts GG, and 0.5 parts CMC (Fig. 5). Compared to the control bread, the specific volume increased by 32%, the crumb grain was improved from a score of 5.5 to 6, and the increase in crumb firmness during storage was reduced by 50%. Initial crumb firmness was evaluated as "tender" (the control bread was "coarse"), crumb elasticity as "fairly good," and the taste was typical for this type of bread. The acceptable ranges of response for the dependent variables were a sufficient crumb elasticity.

CONCLUSIONS

This study showed that properties of whole wheat flour dough and whole wheat bread are significantly affected by emulsifiers and hydrocolloids. At constant medium levels of MDG (0.3 parts) and CMC (0.5 parts) and increasing concentrations of DATEM and GG, the fermentation stability increased, whereas final proof time, dough elasticity, and dough height decreased. Observations of the functional properties of the bread were an increase in specific volume, a reduction of crumb elasticity, and an increase in crumb firmness during storage. A whole wheat bread of good quality can be made by adding 0.3 parts MDG, 0.6 parts DATEM, 0.15 parts GG, and 0.5 parts CMC.

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[Received May 21, 1992. Accepted December 12, 1992.]