Optimizing of Rye Bread Recipes Containing Mono-Diglyceride, Guar Gum, and Carboxymethylcellulose Using a Maturograph and an Ovenrise Recorder[1]

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ABSTRACT

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To determine and optimize the functional properties of rye flour doughs and rye bread, an expanded fractionated factorial test plan and a multi-polynomial regression analysis were used to determine the proportions of three commercial additives. The additives utilized were mono-diglyceride (MDG), guar gum (GUAR), and carboxymethylcellulose (CMC). The optimal final proof time for rye pan bread was determined with a maturograph. Baking behavior was determined with an ovenrise recorder. The specific volume, as well as the porous structure of the crumb and the shelf life, could be improved without altering the crumb elasticity by adding 0.8 parts MDG, 0.6 parts CMC, and 0.3 parts GUAR.

Rye bread, produced from rye flour and rye wholemeal, is an important bread variety in Germany. The quality of rye bread may be improved by adding hydrocolloids and emulsifiers. Numerous experiments for testing the influence of emulsifiers and hydrocolloids on the properties of wheat flour doughs and breads have been reported (Stefanis et al 1977, Pomeranz 1980, Schuster and Adams 1983, Riisom et al 1984, Mettler et al 1991a–d). In contrast, there are no results available concerning the effects of these additives on rye flour doughs and rye bread.

The present work introduces the use of the maturograph and the ovenrise recorder (Brabender oHG, Duisburg, Germany) for optimizing the fermentation and baking properties of rye flour doughs containing mono-diglyceride (MDG), guar gum (GUAR), and carboxymethylcellulose (CMC). In earlier experiments, these two measuring instruments were used to determine and optimize the influence of specific additives on the fermentation and baking quality of wheat flour doughs (Seibel and Crommentuyn 1963a,b; Mettler et al 1991a). This knowledge made it possible to determine and optimize the functional properties of rye flour doughs and rye bread.

MATERIALS AND METHODS

Materials

The specifics of the rye flour used (type 997) were: falling number 215, maltose number 2.7, amylogram viscosity ~525 BU at maximum temperature of 67.5°C, and ash content 0.86 (db). The emulsifiers used were mono- and diglycerides of fatty acids (Chemische Fabrik Grünau GmbH, Illertissen, Germany). The MDG had a total monoglyceride content of 90–95 %. The fatty acid component consisted mainly of stearic and palmitic acids. The emulsifiers were added as a powder. The hydrocolloids used were GUAR (Ulmer Spatz Vertriebsgesellschaft für Backmittel mbH, New Ulm, Germany) and CMC (Kalle AG, Wiesbaden-Biebrich, Germany).

Maturograph

Rheological behavior of rye flour dough during fermentation in the maturograph was determined using a modification of the method currently used for wheat flour doughs, as shown in Figure 1 (Seibel and Crommentuyn 1963a,b; Mettler 1990). Bread processing procedures for rye bread are shown in Figure 2. Maturograph measurements were made concurrently with bread processing.

One sample from the bread dough was taken for measuring the final proof time in the maturograph. The remainder was tinned and put in the fermentation cabinet. When the final proof time was indicated by the maturograph, the tinned bread was put in the oven. Best bread shape was always in compliance with the final proof time shown in the maturogram. This is evidence that the predicted optimal proof time corresponds with the actual proof time of the bread. Optimal final proof time (min) for wheat flour doughs was attained at the highest point in the decompressed fermentation curve (Fig. 3).

Rheological behavior of rye flour dough is different than that of wheat flour dough. The maturograph method was modified

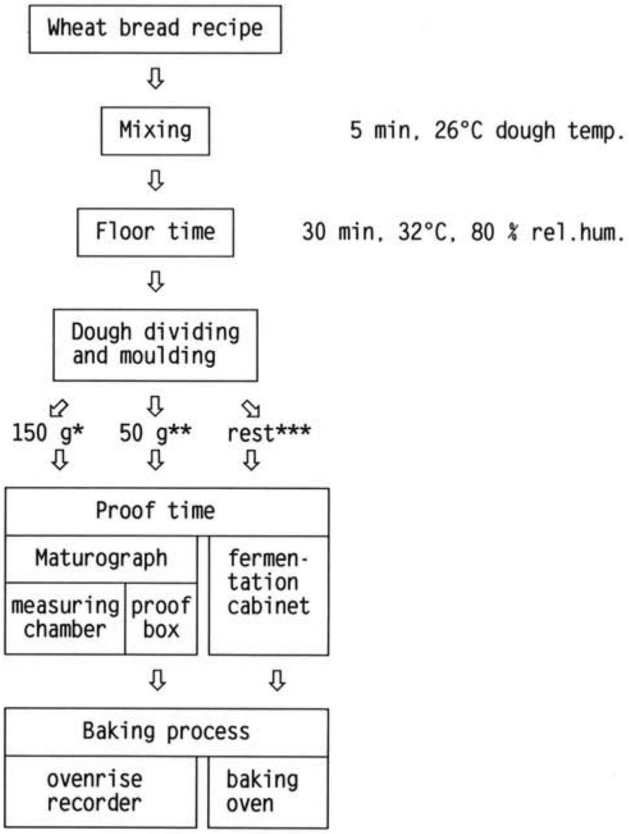

Fig. 1. Method for processing wheat flour dough. * = Dough for maturograph; ** = dough for ovenrise recorder; *** = dough for pan bread.

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in that, due to the lesser dough height, the portion of rye flour dough was doubled to 300 g for better maturograph differentiation of the effects of the additives (Fig. 2). Moreover, rye flour doughs have less gas retention than wheat flour doughs. The gas production of the yeast will produce a broken upper crust in rye bread if baked at the optimal, maximum dough position used for wheat bread in the maturogram. To obtain a well-formed rye bread, it was necessary to extend the final fermentation time to reduce the ovenrise. Numerous maturographical studies revealed that the optimum final proof time of rye doughs in pans is reached after passing the maximum dough height with a clear decline in the level of the dough position (Fig. 4) (Mettler et al 1992). For bread dough in a baking pan, the final proof time was 78 min. For the same dough, not in a pan, optimal proof time was 60 min, the maturogram maximum (Fig. 4). Dough height and proof time were the two parameters used in this study to describe the influence of the additives on dough rheology.

Ovenrise Recorder

Baking quality is determined by the optimal fermentation ripeness in an ovenrise recorder, which is similar to a fryer. In a modification of the method used for wheat dough (Mettler et al 1992), a piece of rye dough (165 g) was used to displace an oil volume of 156 ml. The buoyancy was sufficient to compensate for the load on the balance of the dough and the hanging system.

After the fermentation time indicated by the maturograph, the ripe dough was placed into the ovenrise recorder oil bath. During a 22-min baking period, the temperature of the oil rises from 30 to 100° C. As the ripe dough is heated, the increase in volume creates a buoyancy that is registered by the ovenrise scale. The ovenrise of the last 10 min of baking is identified as final rise. Both parameters, ovenrise and final rise, are measured in ovenrise units. Figure 5 shows the comparative ovenrise curves of wheat and rye doughs. Ovenrise and final rise were used to characterize the baking behavior of the dough containing additives.

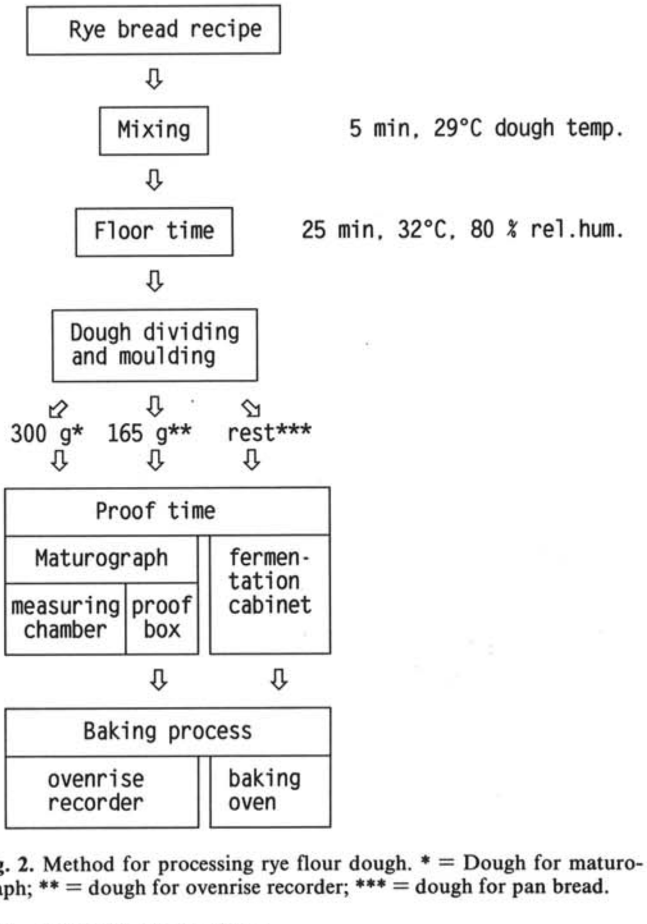

Fig. 2. Method for processing rye flour dough. * = Dough for maturograph; ** = dough for ovenrise recorder; *** = dough for pan bread.

Bread Production

The rye flour bread (pan bread) was produced using the lactic acid baking test (Drews 1970, Arbeitsgemeinschaft Getreideforschung 1978). Mixing time of the rye dough was held constant over the experimental design. The adsorption of the dough was constant, relative to the quality of the flour. Doughs containing hydrocolloids used additional water (Table I). Absorption capacities of the hydrocolloids were determined previously (Mettler et al 1991a). Bread production followed an expanded, fractionated test plan (Table II, III) (Davies 1954, Murphy 1977, Mettler and Seibel 1993).

Sensory Evaluation

Sensory evaluation of the bread was performed by a specially trained three-person team. Bread was stored in polyethylene bags for ~24 hr at room temperature. The assessment criteria of the lactic acid baking test (Arbeitsgemeinschaft Getreideforschung 1978) was used for the evaluation.

For quantitative assessment of the crumb grain, every designation was coded by a dimensionless crumb-grain value. Crumb grain designations of "very good to good", "good", "still good", and "satisfactory" were given crumb grain values of 5, 0, −5, and −10, respectively. These values were used for statistical evaluation.

Results of the sensory evaluation of crumb elasticity were assigned quality numbers according to Dallmann (1958). Crumb

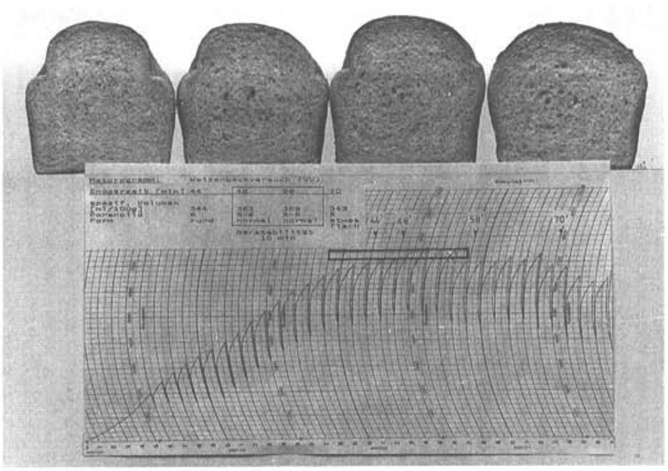

Fig. 3. Maturograph optimization of final proof time for wheat bread (58 min).

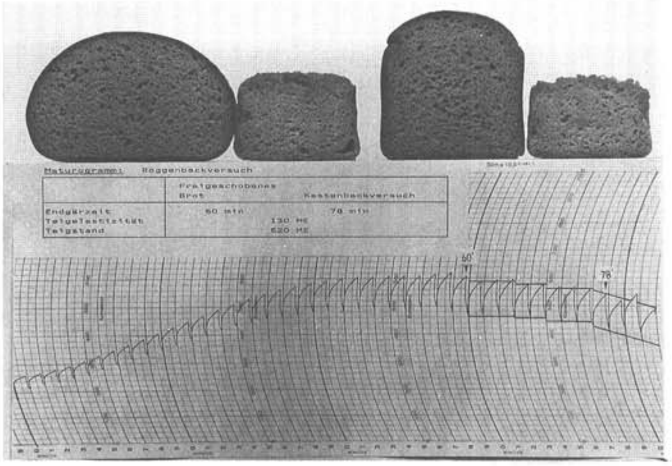

Fig. 4. Maturograph optimization of final proof time for rye loaf bread (60 min) and rye pan bread (78 min). Next to the baked breads are loaves from ovenrise recorder.

elasticity designations of "good", "still good", "satisfactory", "deficient", and "unsatisfactory" were given quality numbers of 0, −5, −10, −75, and −100, respectively. These numbers were used for statistical evaluation.

Rheological and Volume Measurements

Crumb firmness was tested using an LFRA-texture analyzer (Stevens & Son Ltd., England) as described in Mettler et al (1991d). Testing was done on the first, third, and fifth day of storage. The values ascertained were characterized as a straight regression dependent upon the storage time, whose regression coefficient ($\delta Kf/\delta t$ = increase in crumb firmness vs. storage time), flowed into the multipolynomial evaluation. Bread volume was measured by rapeseed displacement, and specific volume was calculated as ml/100 g of bread crumb.

TABLE I
Formula for Rye Bread

Constant Parts		Variable Parts	
Rye flour	1.00	Emulsifier	
Salt	1.5	Mono-diglycerid	0.6/1.2
Yeast	1.0		
Lactic acid	0.8	Hydrocolloids	
Water	73.0	Guar gum	0.6/1.2
		Carboximethylcellulose	0.6/1.2
		Additional water with 0.6/1.2 parts of hydrocolloids:	
		With guar gum 6.0/12.0 parts of water	
		With carboxyethylcellulose parts of water	4.2/8.4

TABLE II
Expanded Fractional Test Plan for Examiniation of the Effects of the Additives Based Upon the Basic Recipe[a]

	x_1	−1			0			1		
x_3	x_2	−1	0	1	−1	0	1	−1	0	1
−1		x	x	x	x		x	x		x
0		x	x			x			x	
1		x		x	x		x	x		x

[a] x_1 = GUAR; x_2 = CMC; x_3 = MDG.

TABLE III
Transformation Formula for Calculating the Absolute Amounts of Additives

Variable[a]	Ingredient [*T*]	Parts [*T*] per Step (ZS)			Transformation Formula
x_1	Guar gum	0	0.6	1.2	ZS − 0.6/0.6
x_2	Carboxymethylcellulose	0	0.6	1.2	ZS − 0.6/0.6
x_3	Mono-diglyceride	0	0.6	1.2	ZS − 0.6/0.6

[a] x_1 = GUAR; x_2 = CMC; x_3 = MDG.

Experimental Design

A response surface methodology (RSM) study (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 three independent variables (MDG, GUAR, CMC) were selected. The complete experimental design, three factors at three levels (3^3), required 27 formula combinations. On a basis of an expanded fractionated factorial design, the number could be reduced to 17 (Table II). Concentration levels of the independent emulsifier and hydrocolloid variables were calculated using the formulas given in Table III. Dependent variables showing dough

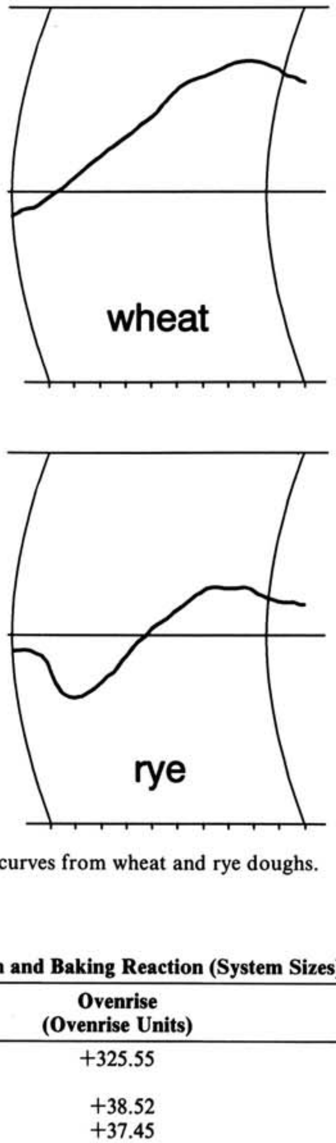

Fig. 5. Ovenrise curves from wheat and rye doughs.

TABLE IV
Regression Coefficient for Quantitative Characterization of the Fermentation and Baking Reaction (System Sizes)

$f(x)$ =[a]	Proof Time (min)	Dough Height (Maturograph Units)	Ovenrise (Ovenrise Units)	Final Rise (Ovenrise Units)
a_0	+94.07	+643.93	+325.55	+238.15
Linear				
$+ a_1 x_1$	+6.64	+15.58	+38.52	+40.91
$+ a_2 x_2$	−1.07	−70.59	+37.45	+39.68
$+ a_3 x_3$	−0.03	+8.92	+16.85	+28.41
Quadratic				
$+ a_4 x_1^2$	−1.46	+12.13	−21.39	−15.09
$+ a_5 x_2^2$	−0.93	+10.59	−4.45	−22.68
$+ a_6 x_3^2$	+1.37	+0.46	+1.94	−21.34
Interactive				
$+ a_7 x_1 x_2$	−0.46	−4.63	+8.47	−6.13
$+ a_8 x_1 x_3$	−0.67	−12.50	−6.67	−15.42
$+ a_9 x_2 x_3$	+0.04	+5.37	−16.53	−0.11
$+ a_{10} x_1 x_2 x_3$	−0.00	−7.50	−6.25	−15.62

[a] x_1 = MDG; x_2 = GUAR; x_3 = CMC.

TABLE V

Statistical Analysis of Functional Connection Between System and Influence Factors

$f(x) =$	Proof Time (min)	Dough Height (Maturograph Units)	Ovenrise (Ovenrise Units)	Final Rise (Ovenrise Units)
Function				
r	0.98	0.98	0.98	0.98
S [%]	99.80**[a]	99.75*	99.88**	99.84**
F-value[b]	18.64*	13.21*	17.05**	15.68**
System Sizes				
$\pm f(x)$	0.84	10.89	8.04	8.54
δ	0.69	7.32	5.97	8.69

[a] * = $P < 0.05$, ** = $P < 0.01$.

[b] F-distribution at 11 degrees of freedom: $F = 4.06$; $S = 95\%$.

characteristics for each combination were final proof time, dough height, ovenrise, and final rise. 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 analyses. Further statistic terms (statistical security [S], the variance homogenity [F] and the correlation coefficient [r]) were employed to control the correlations calculated.

The starting concentrations were determined in preliminary baking tests (Mettler et al 1992). 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 (MDG and GUAR); CMC was held at constant medium level.

RESULTS AND DISCUSSION

After successfully modifying the methods for evaluating rye flour dough using a maturograph and an ovenrise recorder, the rheological behavior of the dough containing MDG, GUAR, and CMC was evaluated in relation to the functional end product properties.

Reproducible results were obtained with rye flour doughs by using modifications of maturograph and ovenrise methods previously used to identify the fermentation behavior of wheat flour doughs (Seibel and Crommentuyn 1963a,b). All results had great statistical certitude and high F-value significance (Tables IV and V).

After establishing the rheological parameters for a sample taken from the processed dough, the pan bread was put in the oven, using the final proof time given by the maturograph. The round and regular shape of the baked loaves confirmed that the proof time given by the maturograph was correct. Correlation between maturograph results and proof time of the processed bread and correlation between bread volume and volume achieved in the ovenrise recorder was reported earlier (Mettler et al 1992).

Effects of Additives Measured by Maturograh and Ovenrise Recorder

The final proof time was largely extended by MDG, while the addition of GUAR and CMC clearly shortened the proof time. The extending influence of MDG on the final proof time cannot be effected with the simultaneous addition of GUAR and CMC. The improvement of final proof time using MDG leads to increased dough height. GUAR has a strong shortening effect on final proof time because of the high water content of doughs. Doughs containing only CMC have improved gas retention and dough height.

All additives increased ovenrise and final rise (Table IV, Fig. 6). As observed in wheat flour doughs (Mettler et al 1991c), final rise was affected by the complexing activity of the emulsifier with the rye starch (complexed starch absorbs less water, while the pressure of the gelatinized starch on the extension of the pores is reduced) and the higher water content of the doughs prepared with GUAR (1:10 parts water) and CMC (1:7 parts water). In doughs prepared with GUAR, the high water content has a negative effect on dough height but, on the other hand, it improves ovenrise.

The fermentation of the rye flour doughs containing additives can be described with great statistical certitude and high F-value significance (Tables IV and V).

Effect of the Additives on Functional Properties

Specific volume is increased by the addition of MDG (+4.34 ×1) and GUAR (+2.62 ×2). The opposite is true for the addition of CMC (−0.66 ×3), which has a negative influence that cannot be fully compensated by the MDG (+1.25 ×1 ×2 ×3). The addition of GUAR has a positive total interactive effect (Table VI, Fig. 7).

The highest water absorption of GUAR (1:10 parts water) significantly improves the crumb grain. MDG has a less positive effect on the desired size than CMC. To attain a positive interactive effect, the combination of all additives is required (Table VI, Fig. 7).

The clearest weakness in elasticity occurs after adding GUAR

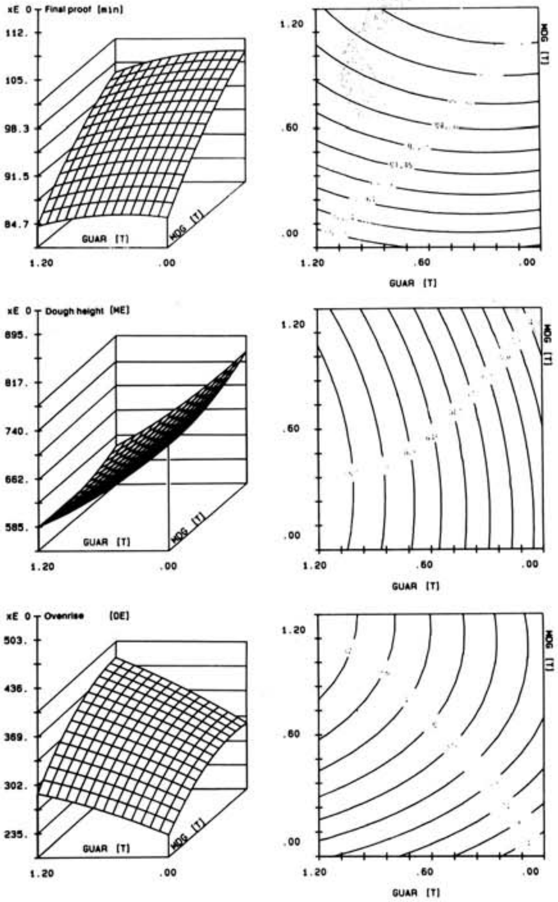

Fig. 6. Effect of additives on functional properties of rye dough were determined by three-dimensional diagrams and contour plots for each quality parameter generated as a function of two variables. MDG = mono-diglyceride; GUAR = guar gum. The level of carboxymethylcellulose remained constant.

(−20.71 ×2) followed by CMC and MDG. When GUAR and CMC were added together, the crumb elasticity was less affected (−14.24 ×2 ×3). No synergistic weakening of the crumb elasticity could be observed when GUAR and CMC were combined with MDG (+4.62 ×1 ×2 ×3) (Table VI).

The crumb remains softer with the addition of GUAR. The increase in crumb firmness was significantly negative (−13.18 ×2). This could be due to the high water content of the doughs prepared with GUAR. MDG and CMC also reduced the firming of the bread within five days. But their effect was not as important as the softening effect of GUAR (−6.69 ×1, −5.07 ×3). The combination of additives, especially MDG and GUAR, lead to a distinct improvement in the crumb softness during storage (Table VI, Fig. 7). Tables VI and VII give the statistical data for the functional properties of the end-product.

Optimizing Functional Properties in Rye Bread

To obtain a good bread, we need an optimum in specific volume, crumb grain, and crumb elasticity and a minimum in crumb firmness. As explained above, the soft GUAR bread is not sufficiently elastic. Optimizing the functional bread properties requires finding a compromise between the examined parameters.

TABLE VI
Regression Coefficient for the Quantitative Characterization of the End Product Properties (Target Sizes)

$f(x) =$[a]	Specific Volume	Crumb Grain	Crumb Elasticity	$\delta Kf/\delta t$
Constants				
a_0	+181.78 ml/100g	±1.63	−4.19	+73.14 g/day
Linear				
$+ a_1 x_1$	+4.34	+0.29	−4.84	−6.69
$+ a_2 x_2$	+2.62	+3.20	−20.71	−13.18
$+ a_3 x_3$	−0.66	+1.96	−13.67	−5.07
Quadratic				
$+ a_4 x_1^2$	−5.36	+0.65	−4.21	−1.77
$+ a_5 x_2^2$	+2.78	+0.80	−12.69	+3.43
$+ a_6 x_3^2$	+0.39	−1.44	−2.30	−6.96
Interactive				
$+ a_7 x_1 x_2$	+1.86	−1.06	−3.49	−2.71
$+ a_8 x_1 x_3$	−0.25	−0.42	+0.42	−1.27
$+ a_9 x_2 x_3$	−1.89	−2.31	−14.24	−2.40
$+ a_{10} x_1 x_2 x_3$	+1.25	+0.00	+4.62	−2.47

[a] x_1 = MDG; x_2 = GUAR; x_3 = CMC.

The optimum amount of additives for rye bread was obtained by superimposing the contour plots of the bread quality parameters (specific volume, crumb grain, crumb elasticity, and crumb firmness during storage) as a function of GUAR and MDG. The optimum (cross-hatched) area in Figure 8 shows the required additions of GUAR (0.1–0.6) and MDG (0.4–0.9). This method only allowed the optimization with two additives. CMC was, therefore, kept at a constant medium level. The amount of CMC was not increased because there was no really positive impact on the volume. CMC was also not as good as GUAR and MDG in reducing the firming of the bread. On the other hand, the addition of CMC did slightly improve crumb grain and had a positive result on crumb elasticity when combined with MDG and in the overall interactive effect with MDG and GUAR (Table VI). Figure 9 shows the maturogram and the ovenrise curve of the optimal formula. In the baking test, a rye bread of high quality could be produced using the calculated optimum formulation of: 0.8 parts MDG, 0.3 parts GUAR, and 0.6 parts CMC (Fig. 10). The final proof time was 96 min.

Adding MDG lead to a clear increase in volume, due to a longer final proof time and a greater ovenrise. As observed in wheat flour doughs (Mettler 1991c), the increase of ovenrise, and especially the increase of the final rise, in doughs prepared with

TABLE VII
Statistical Analysis of the Functional Connection Between Target and Influence Factors

$f(x) =$[a]	Specific Volume [ml/100g]	Crumb Grain	Crumb Elasticity	$\delta Kf/\delta t$ (g/d)
Function				
r	0.96	0.94	0.98	0.98
S [%]	98.97**[a]	95.59*	99.89**	99.88**
F-value[b]	7.76*	4.29*	17.57**	17.20**
System Sizes				
$\pm f(x)$	1.07 ml/100g	1.32	2.54	2.14 g/d
δ	1.06 ml/100g	0.72	2.81	1.81 g/d

[a] * = $P < 0.05$, ** = $P < 0.01$.

[b] F-distribution at 11 degrees of freedom: $F = 4.06$; $S = 95\%$.

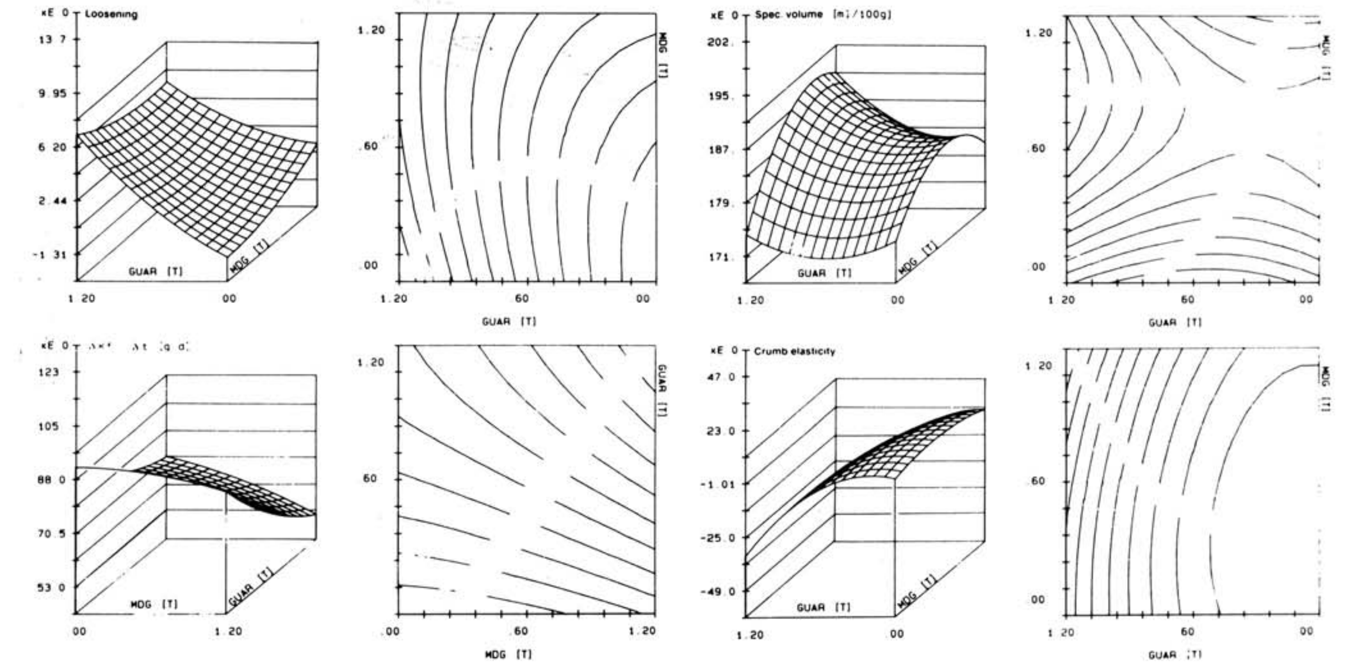

Fig. 7. Effect of additives on functional properties of the end product were determined by three-dimensional diagrams and contour plots for each quality parameter generated as a function of two variables. MDG = mono-diglyceride; GUAR = guar gum. The level of carboxymethylcellulose remained constant.

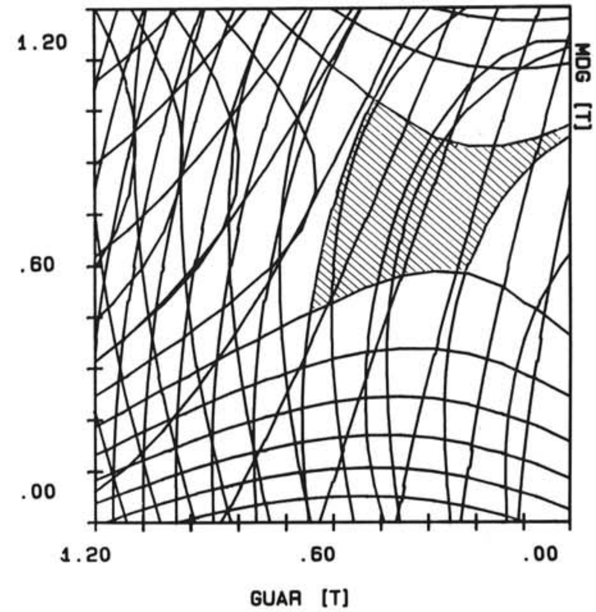

Fig. 8. Optimum amount of additives for rye bread was obtained by superimposing the contour plots of the bread quality parameters (specific volume, crumb grain, crumb elasticity, and crumb firmness during storage). MDG = mono-diglyceride; GUAR = guar gum. The level of carboxymethylcellulose remained constant.

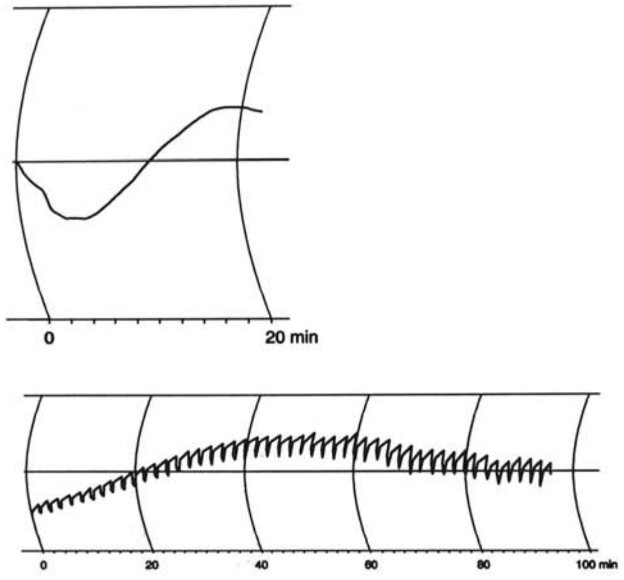

Fig. 9. Maturogram and ovenrise curve of the optimal formula.

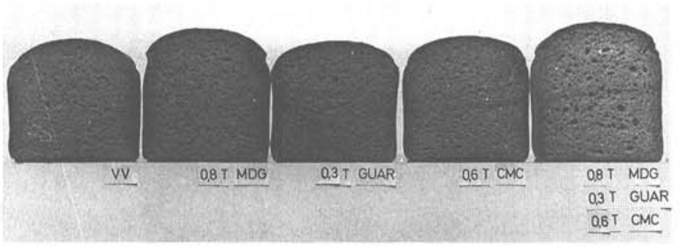

Fig. 10. Baking test results. High quality rye bread was produced using the calculated optimum formulation of: 0.8 parts mono-diglyceride (MDG), 0.3 parts guar gum (GUAR), and 0.6 parts carboxymethylcellulose (CMC).

MDG is a result of the diminished gelatinization of the starch that promoted the gas expansion. With the addition of GUAR and CMC, the specific volume and crumb grain further increased, and crumb firmness decreased. Because it leads to a strong negative effect on crumb elasticity, the amount of GUAR added has to be less than the amount of CMC (Fig. 10). Compared to the control test, the specific volume of the optimized rye bread was improved by 15 to 207 ml/100 g. The crumb grain was "good to very good", the crumb elasticity was "good" with unchanged chewability.

CONCLUSION

To find the best recipe for improving rye bread quality through the addition of hydrocolloids and emulsifiers, optimization of the functional end-product properties on the basis of a fractionated factorial test plan and a multipolynomial regression analysis were investigated. The optimal proof time was determined with the maturograph and the development of the bread volume was determined with the ovenrise recorder. By using 0.8 parts MDG, 0.6 parts CMC, and 0.3 parts GUAR, based on 100 parts flour, a rye bread with optimal loaf volume and a very good crumb structure is achieved.

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