EFFECT OF ADDITIVES ON THE ELASTIC AND PLASTIC PROPERTIES OF BREAD-CRUMB

IV. EFFECT OF SURFACE-ACTIVE AGENTS

By

L. Telegdy Kováts and R. Lásztity

Department of Food Chemistry, Polytechnic University Budapest

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It is an old and in the practice of the baking industry often utilized observation that, especially in the case of products prepared from flours of low grade of grinding, the use of fats in a smaller quantity results in a considerable improvement of quality. Later it turned out that an effect similar to that of the fats can be attained by the addition of lecithin. After World War II the effect of other lipoids, especially of the different monoglycerides, was investigated more and more thoroughly. In recent years the use of other surface-active agents (derivatives of polyoxyethylene, sorbitan-stearates, propyleneglycol-stearates) was also attempted in the baking industry [1, 2]. Experiments were carried out with breads prepared by adding different fatty acids too [3].

From the different surface-active agents, the effect of the glycerol-monostearate and the polyoxy-ethylene-monostearate was studied the most exhaustively. In most case the investigations deal with the problem of inhabiting of bread staling aging. It has been stated that the softness of the crumb is increased and the processes of the bread-staling are slowed down by employing these surface-active additive agents [2, 4, 5, 6, 7, 8, 19]. The volume of the bread is increased, and the distribution of the pores becomes finer and more uniform [2, 4, 7, 9, 10, 15]. A good summary of the listed and other effects of such additives is given by Maes [11]. In connection with the role of fatty acids it is mentioned that results similar to those of the above-enumerated surface-active agents can be attained. The volume is increased, the crumb-porosity is finer and more uniform [3].

The mechanism of the surface-active agent action has been also thoroughly dealt with but being this problem very complicated it is up till now not yet completely and satisfactorily elaborated and solved. The greater part of research workers are of the opinion, that the leading role is played by adsorption phenomena. The correlation between action and chemical structure of the surface-active agents was studied by certain authors too.

In our previous papers [12, 13, 14] the effects of some additives of the baking industry (potatoes, milk, fats) on the elastic and plastic properties of bread-crumb were dealt with. In the present paper investigations on the rheologic properties of the crumb of fresh breads prepared with the addition of some surface-active agents (fatty acids, monoglycerides) are described.

Experimental

Test materials and methods used. Wheat flour of type BL 112 was used for the investigations. The farinographic water-absorbing capacity of the flour amounted to 61,8% and its baking quality was B_2. The fatty acids (oleic acid, palmitic acid) and the monoglyceride (glycerol monostearate) used were of purum grade. The experimental breads were prepared according to the standard prescriptions, with the modifications mentioned in our previous paper [12]. The additives were used during the preparation of the dough in form of aqueous emulsions.

The following tests were carried out on the breads:

Volumenometry, total, permanent and elastic deformations, relative elasticity, apparent modulus of elasticity, apparent plastic viscosity. The first five data were determined as described previously [13]. The apparent modulus of elasticity as well as the apparent plastic viscosity were calculated using of the following formulas:

$$E_{app.} = \frac{P}{2r\pi h_e} \frac{l}{h_e}$$

where $E_{app.}$ = apparent modulus of elasticity
P = total force acting on the pressing body in gs
e = radius of the pressing body
h_e = elastic deformation in mms
l = height of the crumb sample in mms

$$\eta_{pl.\,app.} = \frac{P}{2r\pi\, 0{,}89 h_t} \cdot \frac{l}{h_p} \cdot t$$

where $\eta_{pl.\,app.}$ = apparent plastic viscosity
h_t = total deformation in mms
h_p = plastic deformation in mms
t = action time of the deforming force

The theoretical considerations concerning the calculations were published elsewhere [17, 18].

1. *Rheologic properties of crumb from breads prepared with addition of palmitic acid*

The breads used for the experiments were prepared by adding 0,0%, 0,2%, 0,4%, and 0,8% of palmitic acid (calculated for the flour). The test data are summarized in Diagrams 1, 2, 3, 4 and 5 and in Table 1. The results were worked out by mathematical-statistical methods too, and regression equations as well as correlation coefficients were calculated. The obtained equations and coefficients are as follows:

Total deformation	T_P	$= 6{,}92 + 5{,}40\,p - 5{,}01\,p^2$
	r_{TP}	$= 0{,}515$
Plastic deformation	P_P	$= 1{,}96 + 5{,}12\,p - 4{,}26\,p^2$
	r_{PP}	$= 0{,}500$
Elastic deformation	E_P	$= 4{,}96 + 0{,}28\,p - 0{,}74\,p^2$
	r_{EP}	$= 0{,}147$
Relative elasticity	RE_P	$= 72{,}3 - 44{,}8\,p + 35{,}0\,p^2$
	r_{REP}	$= 0{,}604$
Volume	V_P	$= 883 + 205\,p - 113\,p^2$
	r_{VP}	$= 0{,}759$

where $p = \%$ quantity of palmitic acid used for preparing the bread.

Table 1

Plasticity and viscosity of the crumb of breads prepared with addition of palmitic acid

Series	Palmitic-acid addition %							
	0,0		0,2		0,4		0,8	
	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10⁵ poise	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10⁵ poise	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10⁵ poise	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10⁵ poise
1	3,82	0,460	3,66	0,413	4,01	0,332	5,98	0,548
2	3,82	0,591	8,03	0,349	3,10	0,738	8,60	0,368
3	3,82	0,791	4,84	0,348	3,82	0,303	4,80	0,378
4	3,10	1,720	2,56	0,981	2,29	0,263	4,84	0,348
5	3,49	1,112	2,14	0,572	2,38	0,322	3,36	0,670
6	3,10	1,750	2,56	0,516	3,82	0,303	2,38	0,240
7	2,18	0,779	3,82	0,589	4,18	0,546	2,86	0,338
8	2,29	0,586	2,56	0,404	2,86	0,460	2,18	0,362
9	2,97	0,543	2,38	0,562	2,14	0,311	2,56	0,444
10	3,66	0,524	2,86	0,420	3,82	0,459	3,10	0,393

In Diagram 1 the change of the total deformation is plotted against the quantity of palmitic acid added. It can be seen that the compressibility increases with the increase of the palmitic-acid contents. The measuring points can be well-approximated by a quadratic equation of a parabola. From the value of the correlation coefficient moderately straight correlation can be inferred. As shown by Diagram 2, in case of the plastic deformation the situation is approximately the same as with the total deformation. Under the influence of the addition of palmitic acid, the elastic deformation (Diagram 3) changes only to a small degree. This fact is also shown by the small value of the correlation coefficient. The relative elasticity (Diagram 4) definitely

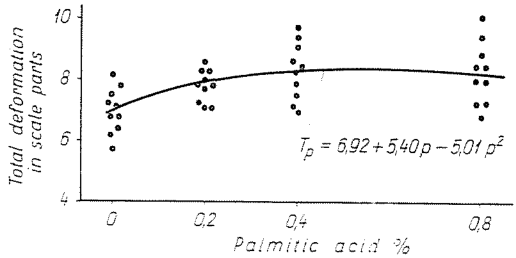

Diagram 1

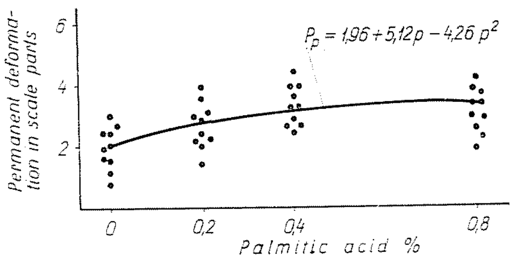

Diagram 2

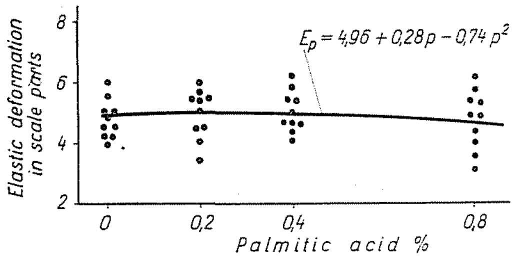

Diagram 3

decreases with the increase of the contents in palmitic acid. Also the volume (Diagram 5) considerably increases with the increase of the fatty-acid addition. In the two latter cases, from the correlations quite closed connection can be inferred.

Summarizing, it can be stated that the rheological properties of the crumb are considerably changed by the addition of palmitic acid. The change of the plastic and elastic properties can be partly traced back to the increase of the volume. In our last paper [14], taking into consideration certain suppositions, calculations were carried out in connection with the increase of deformation taking place under the influence of the volume increase. By investigating the ratio of the average wall thickness of the pores of breads prepared without and with the addition of palmitic acid (calculating on the basis of the volume increase) as well as the ratio of the individual sorts of deformation, data shown in Table 2 are obtained. (Values having index *P* relate to breads prepared with the addition of palmitic acid, while values having index *O* relate to the control breads.)

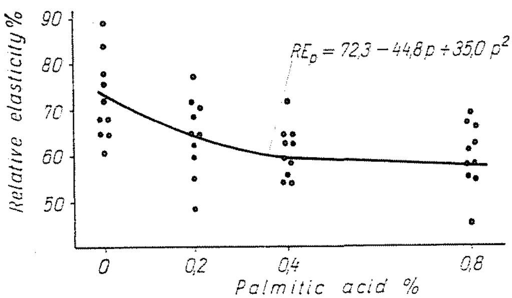

Diagram 4

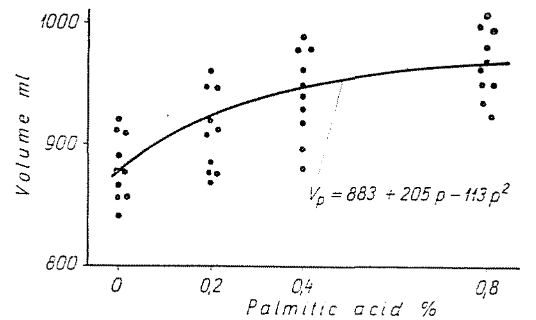

Diagram 5

Table 2

Ratios of the rheological data of breads prepared with and without palmitic acid addition

% quantity of palmitic acid added	$\frac{V_P}{V}$	$\frac{T_P}{T}$	$\frac{P_P}{P}$	$\frac{E_P}{E}$	$\frac{f^*}{f_P^{**}}$
0,2	1,04	1,15	1,44	1,01	1,02
0,4	1,07	1,19	1,70	1,00	1,04
0,8	1,10	1,17	1,73	0,95	1,07

* f = cross-section of the pore walls of control breads

** f_P = pore-wall thickness calculated for breads prepared with palmitic-acid addition

It is shown by the data that the rates of increase of the total and plastic deformations are higher than the decrease of the pore-wall thickness calculated on the basis of the volume increase. From this fact it can be inferred that the changes taking place in connection with the rheological properties are caused not only by the volume increase, but also by the surface-active agents built into the structure of the skeleton of the bread-crumb.

During the preparation of the dough, the surface-active agents, and thus the fatty acids, too, are adsorbed on the developing surfaces. The processes of the water uptake, the swelling as well as the structure formation are considerably influenced by the adsorption.

The effect of individual active substances can be different. By hydrophilizing substances the degree of hydratation is increased, while the strength of bonds between colloidal particles is decreased. Due to hydrophobization of the surfaces of colloidal particles, additives having a hydrophobic effect inhibit water addition, and thus new bonds between the individual colloidal particles can be formed.

The surface-active agent can be distributed on the different boundary surfaces developing in the dough. From these surfaces the surface of gluten and of starch grains are the most important. According to the investigations carried out up till now [20, 21], the active substances influence the water addition of gluten only to a small degree, while the water uptake of starch grains as well as the formation of starch paste are greatly influenced by these substances. The gelation of the starch is inhibited and in finished products the retrogradation of the starch is delayed by active substances. Allusions can be found in the literature in connection with the thinning of gluten fibres forming the skeleton of the dough [11, 20, 22]. On the basis of the latter observation the increased volume of the breads prepared with active substances and the finer distribution of their crumbpores can be explained by the increase of the expansibility of their gluten-skeleton. The deformability to a higher degree of the crumb-skeleton can be traced back, to a certain inhibition of the gelation of the starch grains and to the weaker bonds between the partly gelated starch grains and the gluten skeleton forming the wall of the bread pores. The volume-increasing and crumb-skeleton weakening effect of the palmitic acid decreases with the increase of concentration; this fact is well-illustrated by the regression curves of the second degree.

2. *Rheological properties of crumb from breads prepared with addition of oleic acid*

The investigations were carried out on breads prepared with oleic-acid additions of different quantities (0,0%, 0,2%, 0,4% and 0,%). The test data

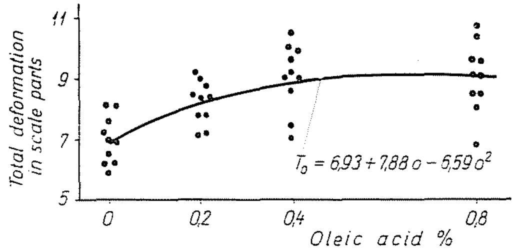

Diagram 6

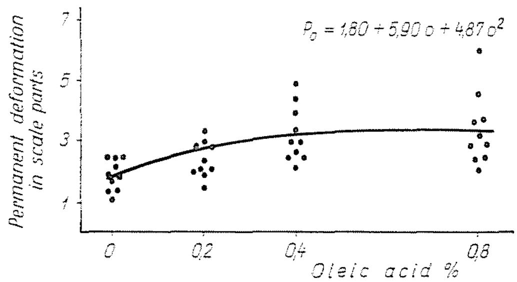

Diagram 7

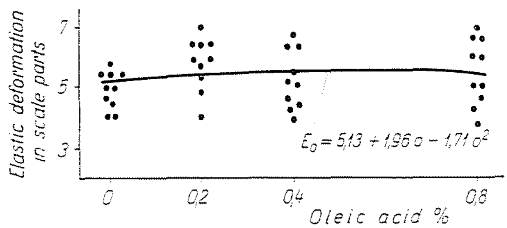

Diagram 8

are summarized by Diagrams 6, 7, 8, 9 and 10 and by Table 3. By evaluating mathematically-statistically the following regression equations and correlation coefficients were obtained:

Total deformation: $T_O = 6{,}93 + 7{,}88\,o - 6{,}59\,o^2$

$r_{TO} = 0{,}707$

Plastic deformation: $P_O = 1{,}80 + 5{,}90\,o - 4{,}87\,o^2$

$r_{PO} = 0{,}583$

Elastic deformation: $E_O = 5{,}13 + 1{,}96\,o - 1{,}71\,o^2$

$r_{EO} = 0{,}234$

Relative elasticity: $RE_O = 73{,}5 - 41{,}4\,o + 35{,}3\,o^2$

$r_{REO} = 0{,}459$

Volume: $V_O = 898 + 265\,o - 205\,o^2$

$r_{VO} = 0{,}806$

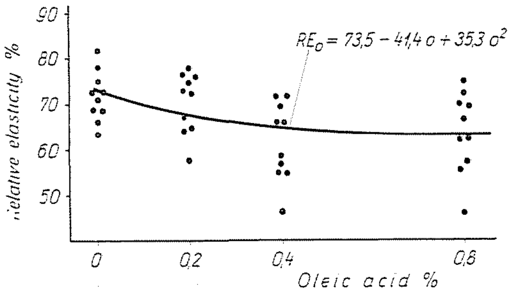

Diagram 9

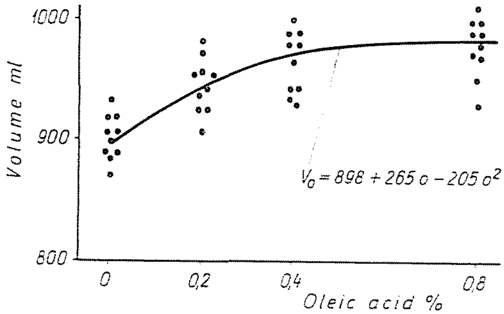

Diagram 10

Table 3

Elasticity and viscosity of the crumb of breads prepared with addition of oleic acid

Series	Oleic-acid addition%							
	0,0		0,2		0,4		0,8	
	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10^8 poise	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10^8 poise	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10^8 poise	$E_{app.}$ g/mm²	$\eta_{pl.\,app.}$ 10^8 poise
1	2,56	0,516	2,14	0,381	4,84	0,394	5,35	0,507
2	3,10	1,720	3,10	0,431	3,82	0,164	1,58	0,436
3	4,84	1,252	1,58	0,434	3,10	0,287	1,83	0,608
4	2,56	0,688	1,83	0,608	3,36	0,248	3,82	0,368
5	4,84	0,636	4,84	0,491	1,68	0,351	3,10	0,157
6	2,56	0,982	1,83	0,608	2,86	0,203	2,14	0,218
7	2,29	0,587	1,83	0,608	3,82	0,590	1,83	0,458
8	3,82	1,150	2,56	0,982	2,56	0,404	3,10	0,345
9	3,10	0,551	2,14	0,645	1,83	0,458	2,14	0,382
10	3,22	0,660	2,14	0,351	1,90	0,442	1,90	0,351

where o = % quantity of the oleic acid (calculated for the flour) used for preparing the bread.

On the basis of the experimental results it can be stated that the change of the individual characteristics is qualitatively the same as in the case of adding palmitic acid. The total deformation, the volume, and the plastic deformation increase with the increase of the oleic-acid addition. It can be said that the correlation is good. The relative elasticity shows a decreasing tendency, while in the case of the elastic deformation the change is of a small degree. The changes of the apparent modulus of elasticity and apparent plastic viscosity are similar to those of the elastic and plastic deformations. As contrasted with the breads prepared with the addition of palmitic acid, the increase of the total and plastic deformations are of a higher degree.

Table 4

Ratios of the rheological data of breads prepared with and without oleic acid addition

% quantity of oleic acid added	$\frac{V_o}{V}$	$\frac{T_o}{T}$	$\frac{P_o}{P}$	$\frac{E_o}{E}$	$\frac{f}{f_o}$
0,2	1,05	1,19	1,55	1,06	1,03
0,4	1,09	1,30	1,88	1,09	1,07
0,8	1,09	1,30	1,89	1,09	1,07

When the degree of change of the rheological properties is compared with the degree of thickening of the pore walls determined in an approximate way by calculation, it is found (see Table 4) that the increase of the deformation exceeds the degree to be expected on the basis of the change of the pore-wall thickness. From this fact again, it can be inferred that the change of the rheological properties is due not only to the volume increase but also to the above-described effects taking place in the skeleton of the crumb.

3. *Rheological properties of the crumb from breads prepared with addition of monoglyceride*

Breads prepared with addition of glycerol-monostearate of different quantities (0,0%, 0,2%, 0,4% and 0,8% calculated to the flour) were used for the experiments. The test results are summarized in Diagrams 11, 12, 13, 14, and 15 as well as in Table 5.

The correlations between the individual characteristics of the crumb and the added glycerol monostearate are illustrated by the following regression equations and correlation coefficients:

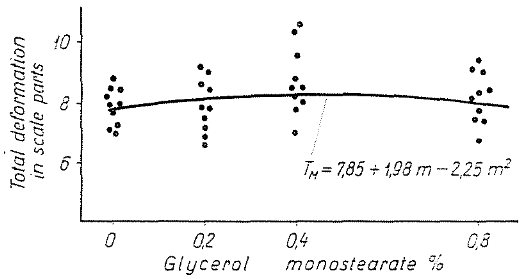

Diagram 11

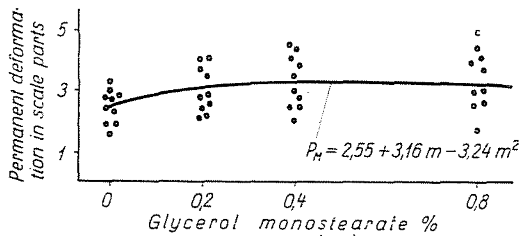

Diagram 12

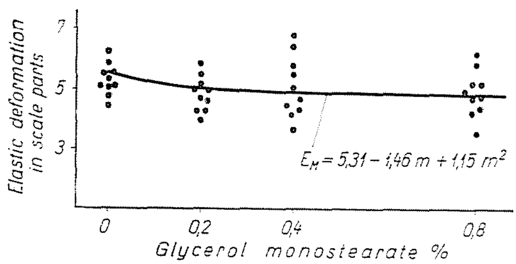

Diagram 13

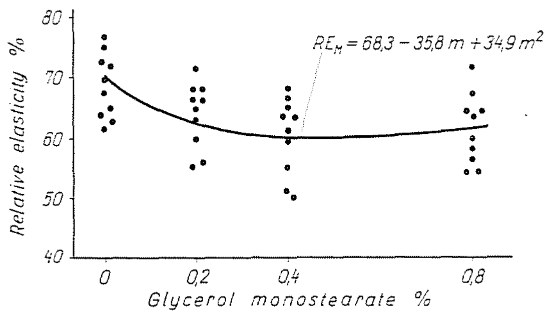

Diagram 14

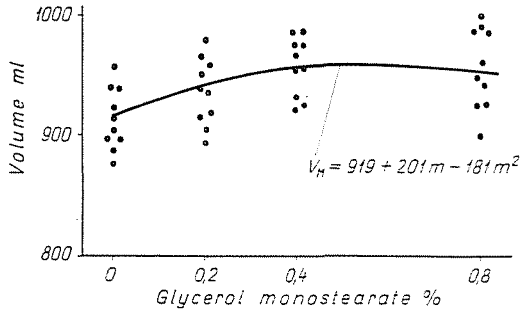

Diagram 15

Table 5

Elasticity and viscosity of the crumb of breads prepared with addition of glycerol monostearate

Series	Glycerol-monostearate addition %							
	$E_{app.}$ g/mm²	$\eta_{pl.\ app.}$ 10^8 poise	$E_{app.}$ g/mm²	$\eta_{pl.\ app.}$ 10^8 poise	$E_{app.}$ g/mm²	$\eta_{pl.\ app.}$ 10^8 poise	$E_{app.}$ g/mm²	$\eta_{pl.\ app.}$ 10^5 poise
1	1,95	0,469	2,97	0,491	2,48	0,417	3,49	0,516
2	3,22	0,589	4,01	0,678	3,82	0,590	3,82	0,327
3	3,36	0,462	2,29	0,429	2,97	0,434	2,97	0,434
4	2,14	0,646	3,10	0,736	4,80	0,348	4,40	0,528
5	2,48	0,678	4,01	0,752	6,33	0,880	6,72	0,563
6	2,48	0,771	3,49	0,543	2,24	0,491	2,86	0,817
7	2,97	0,357	4,51	0,356	4,40	0,263	3,82	0,344
8	2,86	0,401	2,48	0,306	1,83	0,223	2,29	0,330
9	2,86	0,462	3,10	0,287	1,68	0,239	2,02	0,374
10	2,86	0,419	3,82	0,303	4,80	0,261	3,10	0,393

Total deformation: $T_M = 7{,}85 + 1{,}98\, m - 2{,}25\, m^2$

$r_{TM} = 0{,}06$

Plastic deformation: $P_M = 2{,}55 + 3{,}16\, m - 2{,}24\, m^2$

$r_{PM} = 0{,}361$

Elastic deformation: $E_M = 5{,}31 - 1{,}46\, m + 1{,}15\, m^2$

$r_{EM} = 0{,}224$

Relative elasticity: $RE_M = 68{,}3 - 35{,}8\, m + 34{,}9\, m^2$

$r_{REM} = 0{,}436$

Volume: $V_M = 912 + 201\, m - 181\, m^2$

$r_{VM} = 0{,}547$

where m = % quantity (calculated to the flour) of glycerol monostearate used for preparing the bread.

On the basis of the test data it can be seen that the changes taking place under the influence of addition of monoglyceride are generally of smaller degree than in the case of addition of fatty acids. This fact can be observed especially in the case of total deformation when only a very weakly increasing tendency appears and the correlation with the quantity of the monoglyceride is not significant. The volume and the plastic deformation increase significantly, while the relative elasticity decreases by increasing the quantity of the monoglyceride. The decrease of the relative elasticity is of a smaller degree than in the case of fatty acids. The increase of the total deformation corresponds approximately to the value calculated on the basis of change of the pore-wall thickness (see Table 6), while the plastic deformation surpasses this value.

Table 6

Ratios of the rheological data of breads prepared with and without glycerol monostearate addition

% quantity of glycerol monostearate	$\frac{V_M}{V}$	$\frac{T_M}{T}$	$\frac{P_M}{P}$	$\frac{E_M}{E}$	$\frac{f}{f_M}$
0,2	1,04	1,03	1,20	0,96	1,02
0,4	1,06	1,03	1,29	0,92	1,03
0,8	1,05	0,03	1,20	0,92	1,03

On the basis of this fact it can be stated that the skeleton of the crumb is weakened by the addition of the monoglyceride in a smaller degree than in the case of addition of fatty acids.

Thanks are due to Mr. F. ÖRSI, for calculating the regression curves of second degree with an electronic computing machine.

Summary

The rheological properties of the crumb of breads prepared with the addition of different surface-active agents (palmitic acid, oleic acid, glycerol monostearate) have been investigated. The total, plastic and elastic deformations as well as the relative elasticity, the apparent modulus of elasticity, and the apparent plastic viscosity have been determined. It has been stated that the total and permanent deformation and the volume increase when increasing the quantity of the surface-active agent added.

The degree of the plastic deformation is higher in every case, and with the exception of breads prepared with the addition of monoglyceride, the degree of the total deformation is higher than the degree which would correspond to the decrease of the pore-wall thickness calculated on the basis of the volume increase. This fact shows that the change of the rheological properties is a consequence not only of the volume increase but it can also be ascribed to the changes taking place in the skeleton of the crumb under the influence of the surface-active agents. In the case of breads prepared with the additive agents, the elastic deformation changes only to a slight degree, while the relative elasticity decreases in every case. The decrease of the relative elasticity is the smallest in the case of the crumb of breads prepared with addition of monoglyceride.

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Prof. L. Telegdy Kováts
R. Lásztity
Budapest XI., Műegyetem rkp. 3.
Hungary