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

III. EFFECT OF FATS

By

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The physical properties (elasticity, plasticity, porosity etc.) of the crumb are important qualitative characteristics of bakery products. Both from practical and theoretical points of view, it is very important to know these characteristics, as well as the effect of various factors on these properties. In our previous communications [1, 2] investigations in connection with the effect of some additive agents (mashed potatoes, milk) on the physical properties of the crumb of bread were described.

In the present study the effect of other additives often used in the baking industry, namely the effect of various fats on the physical properties of bread-crumb is taken into consideration and the results of our investigations on the subject are summarized.

The effect of various fats on the quality of bread and other products of the baking industry were discussed by numerous research workers. It is generally stated that the crumb of breads prepared with fats has a fine pore distribution, and that the addition of fats always increases the volume of the bread [3, 4, 5, 6]. However, there is no significant difference among the volume-increasing effect of vegetable, animal and mixed fats.

Only few detailed data can be found in the literature on the alterations in the physical properties of the crumb due to fats. Most of the investigations are concerned with the effect of fat-addition on the staling of bread [4, 7, 8, 11].

Experimental

Two flours of type BL 112 with a farinographic water-absorbing capacity of 62.5% and 64.8%, respectively, were used for our investigations. Both flours had a baking quality of B_2. The following fats were used: lard, butter, margarine, refined and unrefined sunflower oil. Test breads are made according to standards [9], with varying quantities of fats mentioned above. In order to secure better mixing the solid fats were always added in molten state.

With the test breads the following investigations were carried out: determination of the volume, determinations of the total, elastic and permanent deformations and of relative elasticity. The same methods were applied to the investigations as described in our previous papers [1, 2], and SZABÓ's experiences [10] collected in the course of his researches were also used.

1. Properties of the crumb of breads prepared with addition of lard

The test breads were made with 0%, 2%, 4%, 8% and 12% of lard calculated to the flour quantity employed. For an easy perusal the results are given in diagrams. The data were also treated by mathematical-statistical methods and the regression equations and correlation coefficients were calculated. The obtained regression equations and corresponding correlation coefficients are as follows:

Total deformation:	$T_L = 0.26\,L + 6.59$	$r_{TL} = 0.845$
Permanent deformation:	$P_L = 0.29\,L + 1.70$	$r_{PL} = 0.825$
Elastic deformation:	$E_L = -0.03\,L + 4.90$	$r_{EL} = -0.168$
Relative elasticity:	$RE_L = -2.31\,L + 73.9$	$r_{REL} = -0.759$
Volume:	$V_L = 25\,L + 970$	$r_{VL} = 0.838$

where L = per cents of lard used for preparing the bread.

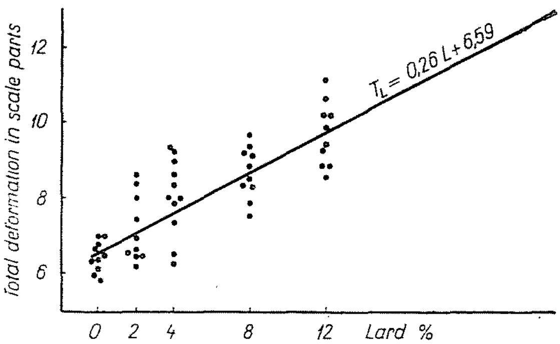

Diagram 1

The data of the total deformation are shown in Diagram 1. It can be seen the total deformation increases with increase of the lard contents and the correlation is quite good. The permanent deformation significantly increases with the lard contents too. (see Diagram 2.) On Diagram 3 the change of the elastic deformation with the lard contents of breads is shown. According to the data, the elastic deformation only changes a little, and the correlation is very slight. As can be seen in Diagram 4 the relative elasticity decreases with the increase of the lard contents. The correlation between the lard contents and the relative elasticity is relatively good. On Diagram 5, the correlation between the volume of test breads and lard contents can be studied; according to this diagram the volume increases with the fat contents, and the correlation is quite good.

As the data shown testify, the physical properties of the bread-crumb significantly change, due to the influence of the added lard. The volume change is the most striking, but the change of the total and permanent deformations

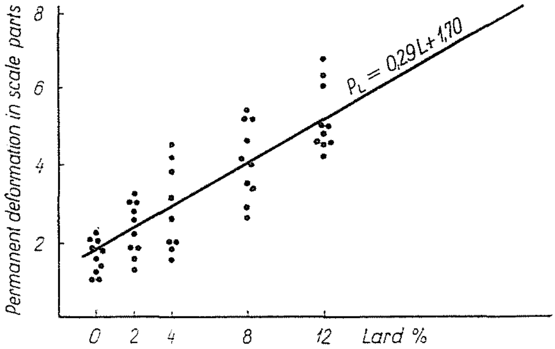

Diagram 2

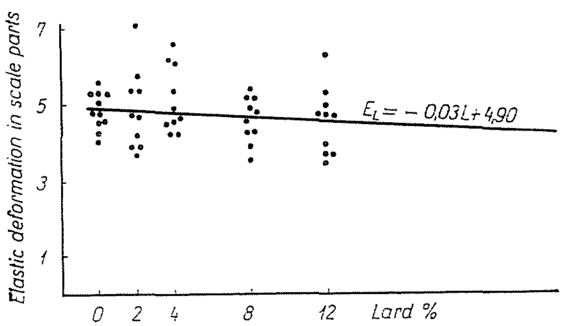

Diagram 3

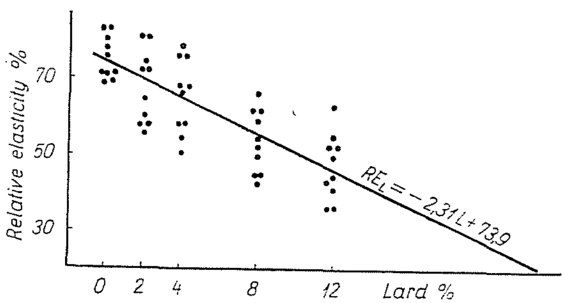

Diagram 4

is significant, too. The change of the deformations can be attributed to two factors: on the one hand to the volume change, because, due to the volume increase, the thickness of the pore walls decreases, and, on the other hand, it can be attributed to the effect of the fat built into the framework of the bread-crumb. It is very difficult to determine reliably the degree of change in

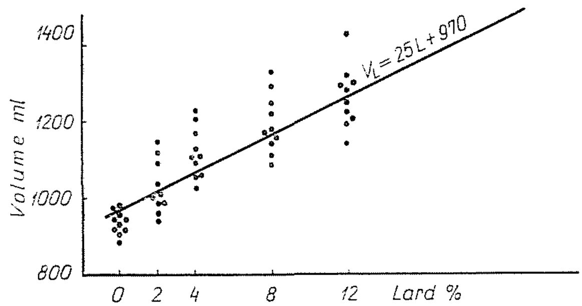

Diagram 5

the thickness and cross-sections of pore walls, furthermore the corresponding change in the deformation due to volume increase. Namely, the pores have no identical dimensions, nor is the distribution of the pores of different dimensions

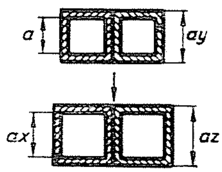

Fig. 1

equally uniform, finally, the pores are not of precisely regular shape. A good and relatively simple approximative calculation can be made in that case if the thickness of the pore walls is identical (see Fig. 1). In that case, the total volume of the bread-crumb can be expressed as follows:

$$V_T = \Sigma a^3 y^3$$

and the total volume of the pores

$$V_B = \Sigma a^3$$

then the total volume of the solid phase is:

$$V_S = V_T - V_B = \Sigma a^3 y^3 - \Sigma a^3$$

if a = edge length of the supposedly hexahedron formed pore

ay = edge length of the hexahedron formed crumb surrounding the pore.

Furthermore, if 1/100 part of the total volume is designated with v and the pore volume expressed in per cents with P, then the following equations can be written:

$$\begin{aligned} V_T &= \Sigma a^3 y^3 = 100\, v \\ V_B &= \Sigma a^3 = Pv \\ V_S &= \Sigma a^3 y^3 - \Sigma a^3 = (100 - P)\, v \end{aligned} \qquad \text{(I)}$$

From the above equations, the value of y can be expressed as follows:

$$y = \sqrt[3]{\frac{100}{P}}$$

The value of a can be expressed from equation I:

$$a = \sqrt[3]{\frac{Pv}{N}}$$

where N = number of the minute elementary hexahedrons.

The thickness of the pore walls can be expressed with the following equations:

$$d = a(y-1) = \sqrt[3]{\frac{Pv}{N}}\left(\sqrt[3]{\frac{100}{P}} - 1\right)$$

while the cross-section of the pore wall of one elementary hexahedron can be calculated as follows:

$$f = a^2(y^2-1) = \sqrt[3]{\left(\frac{Pv}{N}\right)^2}\left(\sqrt[3]{\left(\frac{100}{P}\right)^2} - 1\right) \qquad \text{(II)}$$

If the volume of the bread-crumb increases with V_N per cent, then also the edge length of the elementary hexahedron increases, and will amount to az. The edge length of the internal hexahedron increases, too, and its value amounts to ax. In like manner as above, the following equations can be written for the increased crumb-volume:

Total volume: $V_{T1} = \Sigma\, a^3 z^3$

Pore volume: $V_{B1} = \Sigma\, a^3 x^3$

Volume of the solid phase: $V_{S1} = V_S = \Sigma\, a^3 z^3 - \Sigma\, a^3 x^3$

The following equations can similarly be written:

$$V_{T1} = (100 + V_N)\, v$$

$$V_{B1} = (P + V_N)\, v$$

$$V_{S1} = (100 - P)\, v$$

The values of x and z can be calculated from the above equations as

$$z = \sqrt[3]{\frac{100 + V_N}{P}}$$

and

$$x = \sqrt[3]{\frac{P + V_N}{P}}$$

With the aid of these expressions the thickness of the pore wall of the elementary hexahedron in the increased crumb-volume can be calculated as follows:

$$d_1 = az - ax = a(z - x) = \sqrt[3]{\frac{P_v}{N}} \left[\sqrt[3]{\frac{100 + V_N}{P}} - \sqrt[3]{\frac{P + V_N}{P}} \right]$$

The cross-section of the pore wall in the elementary hexahedron can be expressed by the equation:

$$f_1 = a^2 (z^2 - x^2) = \sqrt[3]{\left(\frac{P_v}{N}\right)^2} \left[\sqrt[3]{\left(\frac{100 + V_N}{P}\right)^2} - \sqrt[3]{\left(\frac{P + V_N}{P}\right)^2} \right] \qquad \text{(III)}$$

According to equations II and III, the ratio of the cross-sections of the pore walls in the original and increased crumb-volume, can be written as follows:

$$\frac{f}{f_1} = \frac{\sqrt[3]{\left(\frac{100}{P}\right)^2} - 1}{\sqrt[3]{\left(\frac{100 + V_N}{P}\right)^2} - \sqrt[3]{\left(\frac{P + V_N}{P}\right)^2}}$$

Supposing that the deformations occurring under the influence of a given force are inversely proportional to the cross-sections of the pore walls, then, knowing the ratio f/f_1, the increase of deformation due to volume increase can be calculated. This calculation gives, of course, only an approximative value because, the exact shape and dimensions of the bread-crumb, the distribution of the pores of various dimensions as well as the occasional qualitative differences of the solid framework forming the pore walls and depending on the situation in the crumb are not known. Furthermore, as mentioned in our first paper [1], during the deformation not only compressive but also bending and shearing forces are acting; thus, the calculation is very complicated. Testing the breads prepared with different fat contents, the ratios of the averf age volume, of the total, permanent, and elastic deformations, as well as o- the pore-wall cross-sections calculated as described above, the data of Table 1 are obtained. (Designations of the Table: V = volume, T = total deformation, P = permanent deformation, E = elastic deformation, f = cross-section of the pore-wall; the values with subscript 1 relate to breads prepared without fat and those with subscript L relate to breads prepared with fat.)

Table 1

Quantity of fat used to prepare the bread %	$\frac{V_L}{V_1}$	$\frac{T_L}{T_1}$	$\frac{P_L}{P_1}$	$\frac{E_L}{E_1}$	$\frac{f_1}{f_L}$
2	1,06	1,08	1,35	0,98	1,03
4	1,10	1,16	1,70	0,97	1,07
8	1,21	1,32	2,35	0,95	1,11
12	1,30	1,47	3,05	0,94	1,14

It is shown by the data of the Table that the degree of increase of the total and plastic deformations with increasing fat contents surpasses the increase of the quotient f_1/f_L obtained with approximating calculation. From this fact, it can be inferred, that the difference between the physical properties of the breads prepared with fat addition and the corresponding properties of the crumb in breads prepared in a similar way but without fat addition is not only due to the volume change. Consequently, the fats building into the framework of the bread-crumb influence the physical properties of the framework, too. The distribution of the fats added while preparing the crumb and the situation of these fats in the paste and after baking in the crumb are not correctly elucidated till now. According to the opinion of most of the research workers, the fats are situated on the boundaries, and they are partly bound by adsorption [6, 8, 12, 13, 14]. It is very difficult to reliably prove the distribution of the fats because that is influenced by several factors as the method of mechanically working the paste, the quantity of the added fats, the size and quality of the surfaces in the system paste-bread, the properties of the added fats (degree of unsaturation, number of the polar groups, etc.) etc. The superficial fat layers of the paste weaken the gluten framework of the paste, make easier the movement of the paste particles side by side which, until a certain limit, advantageously influences the volume of the breads baked from the paste.

As shown by our investigations, the fats to be found in the solid framework of the bread-crumb weaken this framework. The degree of the total deformation increases, that of the permanent deformation significantly increases, while that of the elastic deformation slightly changes with the fat addition. Taking into consideration the degree of decrease of the pore-wall cross-section resulting from the volume increase, it can be stated that the elasticity of the crumb significantly decreases. This fact is evidently shown by the values of the relative elasticity decreasing with the fat content.

2. *Properties of the crumb of breads prepared with butter*

Similarly to the previous test series, 0%, 2%, 4%, 8% and 12% of butter were used for preparing the test breads. The characteristic data of the physical properties of the crumb are summarized on Diagrams 6, 7, 8, 9 and 10. The data

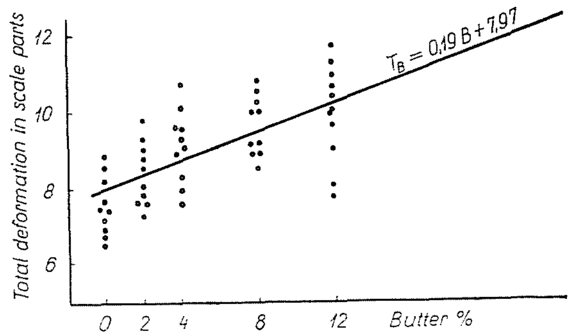

Diagram 6

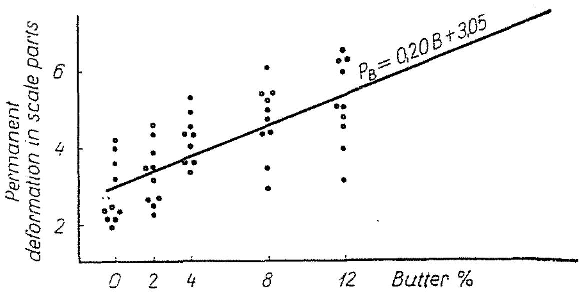

Diagram 7

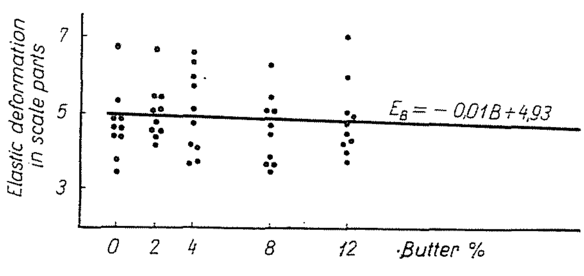

Diagram 8

were treated, as in case of the previous test series, and the following equations for regression lines and correlation coefficients, respectively, were obtained:

Total deformation:	$T_B = 0.19\,B + 7.97$	$r_{TB} =$	0.649
Permanent deformation:	$P_B = 0.20\,B + 3.05$	$r_{PB} =$	0.675

Elastic deformation: $E_B = -0.01\ B + 4.93 \quad r_{EB} = -0.186$

Relative elasticity: $RE_B = -1.32\ B + 62.1 \quad r_{REB} = -0.536$

Volume: $V_B = 15.8\ B + 979 \quad r_{VB} = 0.536$

where $B = \%$ quantity of butter used for preparing the breads.

It is shown by the test data that under the influence of the butter addition, the volume of the breads as well as the total and plastic deformations

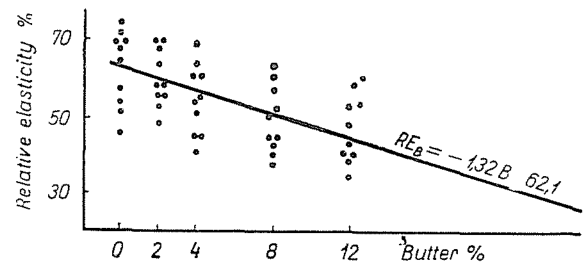

Diagram 9

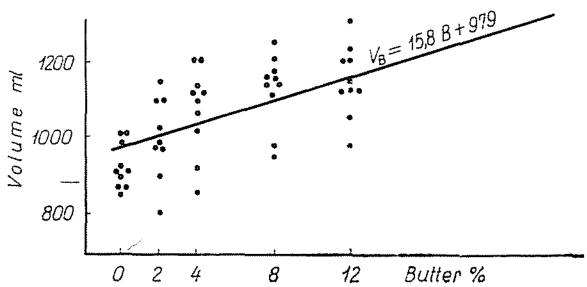

Diagram 10

of the bread-crumb significantly increase. The correlation is significant in all three cases, but the correlation coefficients are lower than in the case of lard. If in this case the degree of the volume increase is compared to the increase of deformation, respectively, as well as the change of the calculated pore-wall cross-section (see Table 2), then it can be seen, that also in this case the increase of the compressibility is higher than the decrease of the calculated pore-wall cross-section. The degree of the elastic deformation slightly changes, moreover it actually slightly decreases with the increase of the total deformation; therefore, the relative elasticity significantly decreases with increase of the butter content.

Table 2

Quantity of butter used to prepare the bread %	$\frac{V_B}{V_1}$	$\frac{T_A}{T_1}$	$\frac{P_B}{P_1}$	$\frac{E_B}{E_1}$	$\frac{f_1}{f_B}$
2	1,03	1,05	1,13	0,996	1,02
4	1,06	1,11	1,26	0,992	1,03
8	1,12	1,19	1,53	0,984	1,06
12	1,19	1,29	1,80	0,976	1,10

3. *Physical properties of the crumb of breads prepared with margarine*

Similarly to the aforesaid, the breads were prepared with addition of 0%, 2%, 4%, 8%, and 12% of margarine. The results of the tests are summarized in Diagrams 11, 12, 13, 14, and 15. The equation of the regression lines characteristic for the correlation between the individual physical properties and the margarine content, as well as the correspondent correlation coefficients are as follows:

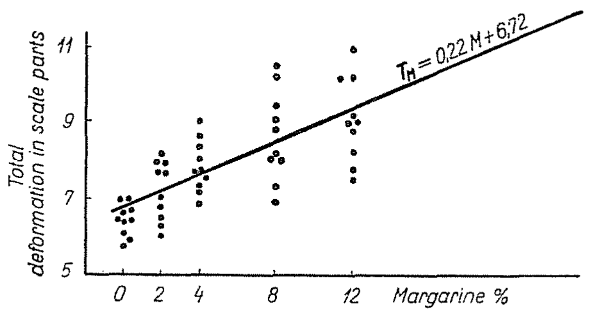

Diagram 11

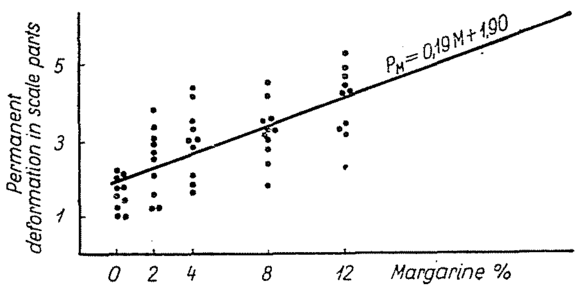

Diagram 12

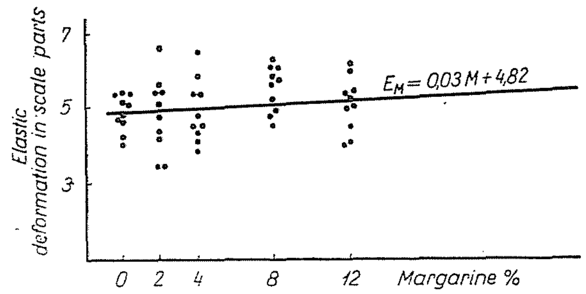

Diagram 13

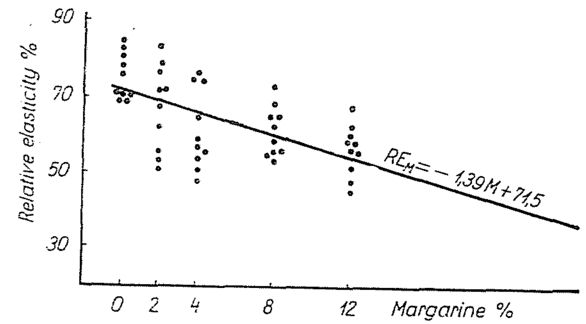

Diagram 14

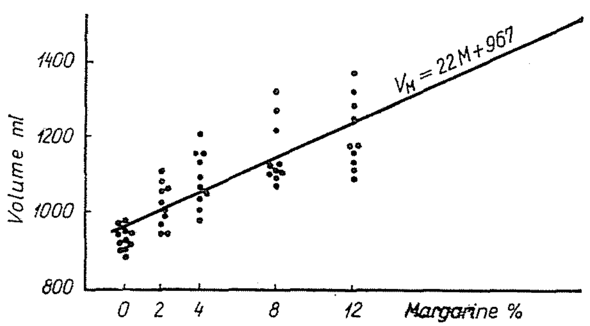

Diagram 15

Total deformation:	$T_M = 0.22\,M + 6.72$	$r_{TM} = 0.713$
Permanent deformation:	$P_M = 0.19\,M + 1.90$	$r_{PM} = 0.703$
Elastic deformation:	$E_M = 0.03\,M + 4.82$	$r_{EM} = 0.169$
Relative elasticity:	$RE_M = -1.39\,M + 71.5$	$r_{REM} = -0.559$
Volume:	$V_M = 22\,M + 967$	$r_{MV} = 0.801$

where $M = \%$ quantity of margarine used to prepare the breads.

It is shown by the test data that under the influence of the margarine addition, similar changes occur in the properties of the crumb as in the cases when adding lard or butter. In contrast to the previous two series, the only difference consists in the fact that the elastic deformation slightly increases with increase of the margarine content.

The correlation between the individual properties and the corresponding values of the bread prepared without margarine is shown in Table 3.

Table 3

Quantity of margarine used to prepare the bread %	$\frac{V_M}{V_1}$	$\frac{T_M}{T_1}$	$\frac{P_M}{P_1}$	$\frac{E_M}{E_1}$	$\frac{f_1}{f_M}$
2	1,04	1,09	1,21	1,01	1,02
4	1,09	1,15	1,42	1,02	1,06
8	1,18	1,28	1,76	1,05	1,10
12	1,28	1,42	2,16	1,08	1,13

It is shown also by the data of Table 3 that in case of margarine the degree of the increase of deformations also surpasses the degree of the decrease of the calculated pore-wall cross-section.

4. *Physical properties of the crumb of breads prepared with refined sunflower oil*

For performing the experiments, from the liquid fats sunflower oil was used in the same quantity as the other fats for the previous test series. The data obtained during these investigations are shown in Diagrams 16, 17, 18, 19, and 20. The equations and correlation coefficients, respectively, obtained by treating the data with mathematical-statistical methods, are the following:

Total deformation: $T_{Or} = 0.17\ Or + 6.64 \quad r_{TOr} = 0.797$

Permanent deformation: $P_{Or} = 0.17\ Or + 1.66 \quad r_{POr} = 0.835$

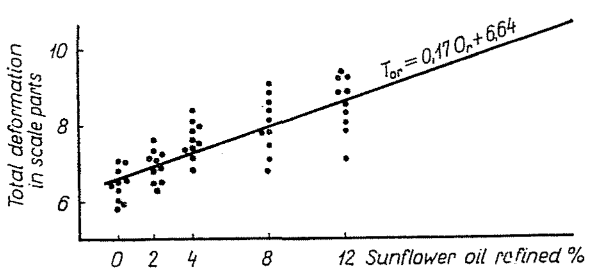

Diagram 16

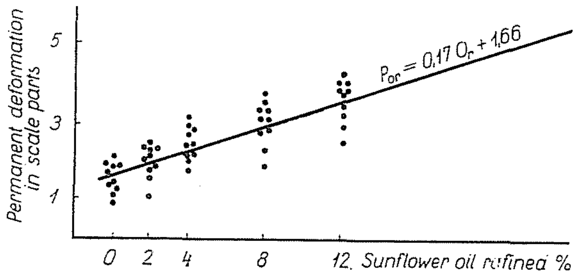

Diagram 17

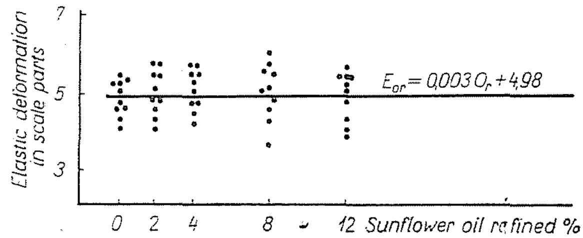

Diagram 18

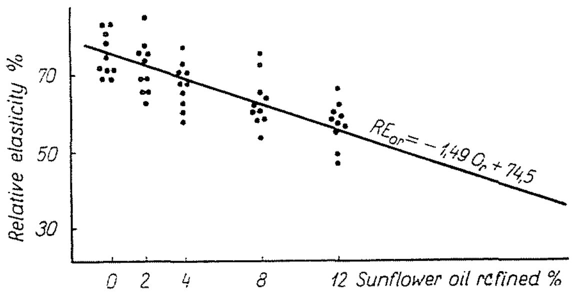

Diagram 19

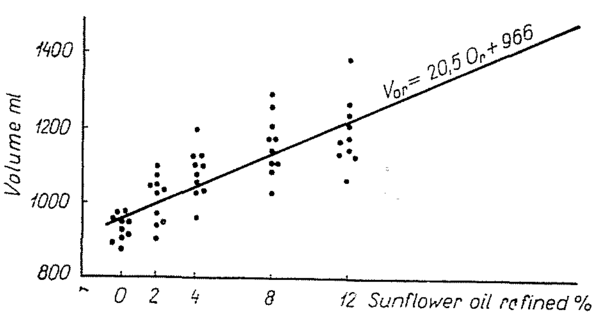

Diagram 20

Elastic deformation: $E_{Or} = 0.003\ Or + 4.98 \quad r_{EOr} = 0.023$

Relative elasticity: $RE_{Or} = -1.49\ Or + 74.5 \quad r_{REOr} = -0.725$

Volume: $V_{Or} = 20.5\ Or + 966 \quad r_{VOr} = 0.787$

where $Or = \%$ of the refined sunflower oil used for preparing the bread.

On basis of the Diagrams it can be seen that the changes of the crumb properties occurring under the influence of the addition of the refined sunflower oil are similar to those observed in the case of the other fats. The correlation between the sunflower-oil content and the individual properties is good, excepting elastic deformation. The change of the calculated pore-wall cross-section and the degree of the change of the individual properties in comparison with the corresponding data of the control bread are shown in Table 4.

Table 4

Quantity of refined sunflower oil used to prepare the bread %	$\frac{V_{Or}}{V_1}$	$\frac{T_{Or}}{T_1}$	$\frac{P_{Or}}{P_1}$	$\frac{f_1}{f_{Or}}$
2	1,04	1,05	1,14	1,02
4	1,08	1,09	1,39	1,06
8	1,16	1,21	1,82	1,08
12	1,23	1,32	2,17	1,11

5. *Physical properties of the crumb of breads prepared with addition of unrefined sunflower oil*

The tests were performed with breads prepared with addition of 0%, 2%, 4%, 8%, and 12% of unrefined oil. The data obtained during the measurements are summarized in Diagrams 21, 22, 23, 24, and 25. The equations of the regression lines giving the correlation between the individual physical

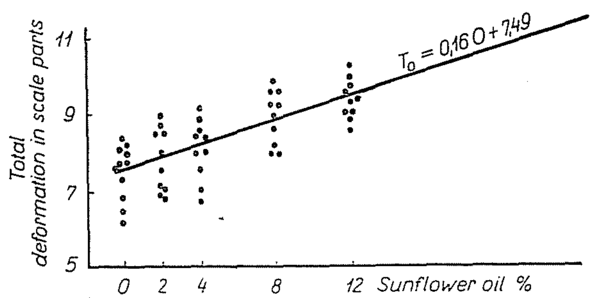

Diagram 21

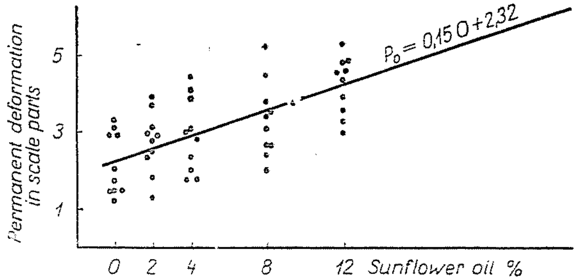

Diagram 22

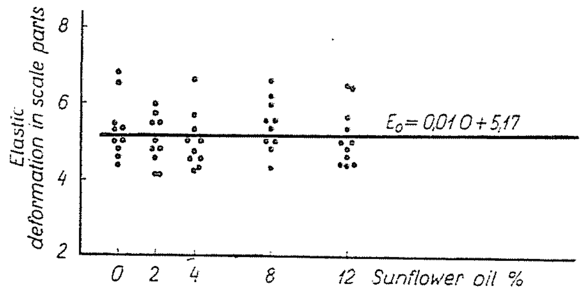

Diagram 23

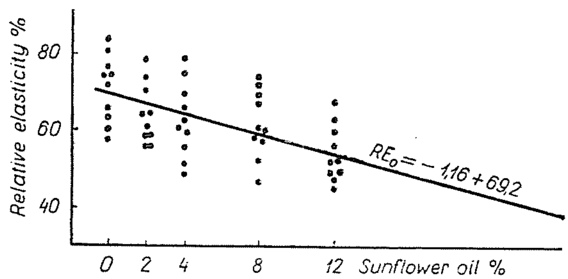

Diagram 24

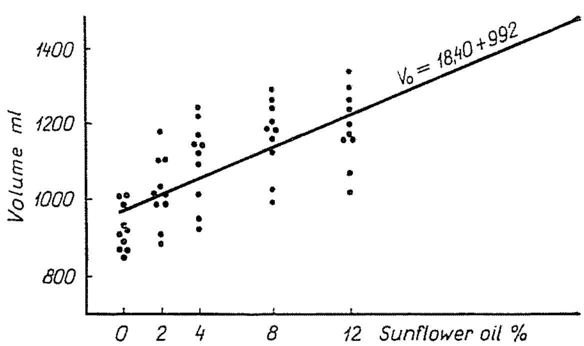

Diagram 25

properties and the content in unrefined sunflower oil as well as the corresponding correlation coefficients are the following:

Total deformation:	$T_O = 0.16\,O + 7.49$	$r_{TO} = 0.718$
Permanent deformation:	$P_O = 0.15\,O + 2.32$	$r_{PO} = 0.617$
Elastic deformation:	$E_O = 0.01\,O + 5.17$	$r_{EO} = 0.047$
Relative elasticity:	$RE_O = -1.16\,O + 69.2$	$r_{REO} = -0.496$
Volume:	$V_O = 18.4\,O + 992$	$r_{VO} = 0.595$

where $O = \%$ quantity of the unrefined sunflower oil used to prepare the bread.

According to the test data, one can see that the three kinds of changes of the deformations as well as the changes of the volume and of the relative elasticity, have the same trend as in the case of breads prepared with refined sunflower oil. The difference consists in the fact that the increase of the plastic deformation is of smaller degree and the change of the relative elasticity is also smaller than in case of the breads prepared with refined oil. It was not possible, however, to prove a significant difference between the effects of the two kinds of oils.

Table 5

Quantity of unrefined sunflower oil used to prepare the bread %	$\frac{V_O}{V_1}$	$\frac{T_O}{T_1}$	$\frac{P_O}{P_1}$	$\frac{f_1}{f_O}$
2	1,03	1,06	1,14	1,02
4	1,07	1,10	1,29	1,04
8	1,15	1,18	1,57	1,08
12	1,23	1,26	1,86	1,11

The correlation between the changes of the individual deformations and the calculated pore-wall cross-section (see Table 5) is similar to that observed in the case of the other experiment series.

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Summary

The physical properties of the crumb of breads prepared with the addition of various fats (lard, butter, margarine, refined and unrefined sunflower oil) were investigated. The total, permanent, and elastic deformations as well as the relative elasticity of the crumb of bread, moreover the volumes of the breads were determined.

It was concluded that the total and permanent deformations of the crumb of breads prepared with fat addition, as well as the volume of the breads increase with the fat content (between the investigated limits). The degree of the increase of the total and permanent deformations is higher than the decrease of the pore-wall cross-section approximately calculated on the basis of the volume increase. From this fact it can be inferred that the change of the degree of deformation is the result not only of the volume increase but also of the structure-weakening effect of the fat penetrating into the framework of the crumb. The elastic deformation of the crumb of breads containing fats only slightly changes with the increase of the fat content and the relative elasticity shows a significant decrease. No significant difference could be shown by the investigations between the effects of the individual fats.

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