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

V. EFFECT OF GLUTEN. SUMMARY AND EVALUATION OF PUBLICATIONS I—V.

By

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It is long known that the gluten proteins have a decisive role in developing the rheological properties of doughs prepared with wheat flour; this was proved by many experimental data and practical observations. In preparing the products of baking industry, considerable transformations take place in the paste during baking. From these transformations, the changes of the gluten proteins and the starch are the most important. By thermal influences the proteins are denatured and coagulate, whereby a considerable part of the water bound by them becomes free. At the same time, under the conditions of the baking, the starch becomes gelled and binds the released water. The characteristic physical properties of the bread-crumb are developed chiefly as a result of these changes. The uninterrupted skeleton of the crumb of bread is formed by the gluten proteins, and the gelatinized starch particles are distributed in this skeleton. As shown e.g. by BECHTEL's and MEISNER's [1] microscopical investigations, the gelatinized starch particles are totally surrounded by the denatured proteins, the single particles are independent, and are generally set in the direction of the longitudinal axis of the protein film or fibre.

On this basis it can be expected that the physical properties of the bread-crumb are decisively influenced by the amount of the gluten proteins, as well as by the ratio of the amount of the gluten proteins and starch. SANDSTEDT, SCHAUMBURG and FLEMING [2] baked breads from doughs prepared with mixtures of gluten and starch of different ratios. Studying the staling of the breads, considerable differences in the compressibility of the crumb could be observed, depending on the gluten content. NIKOLAIEW [3] baked doughs prepared with gluten and with starch alone, and investigated the products thus obtained. When measuring the compressibility and relative elasticity of the crumbs, he observed considerable differences. The compressibility of the crumb of the product prepared with gluten is about twice and the relative elasticity is about one and a half times higher than that of the dough prepared with starch. At the same time it is interesting to note that a product having a definite structure can be prepared with starch as well.

According to experiments carried out in our Institute, the addition of vegetal gums and mucilages to the starch dough makes possible the preparation of products with crumbs fully similar to those of the common products of baking industry. From this fact it can be inferred, that not only the gluten proteins are responsible for developing the crumb-skeleton. During our investigations carried out with flour products [4, 5] it was stated that products of large volume can be prepared even in the case of a small flour content (that is small gluten-protein content) but the strength and elastic properties of the crumb of these products are of considerably inferior quality.

In our present investigations — a continuation of previous researches [6, 7, 8, 9] — the effect of the addition of gluten on the elastic and plastic properties of the bread-crumb has been investigated.

Experimental

Materials and methods

Wheat flour of type BL 112 (ash content not more than 1.12%) was used for the investigations. The water-absorbing capacity amounted to 62.1% measured farinographically. The flour was of B_1 quality and its protein content amounted to 12.6%. The added gluten was prepared from wheat flour. The washed wet gluten was dried in vacuo at a temperature not exceeding 40 °C. The test breads were prepared by the method described in our previous papers. The amount of water to be added was determined with the aid of a farinograph.

With breads the following tests were carried out: measurement of the volume, determination of the total, plastic and elastic deformations, calculation of the relative elasticity, apparent modulus of elasticity and apparent plastic viscosity. The methods of measurement and calculation were described in our previous papers [6, 9].

Rheological properties of the crumb of breads prepared with addition of gluten

The breads used for the tests were prepared with different quantities of added gluten (0%, 2.5%, 5.0% and 7.5% of dry gluten, calculated to the flour). The amount of water required for the preparation of doughs was determined by farinographic tests. In the following the method described previously was employed [6]. In the case of the test breads, the values of the volume and of the total, elastic and plastic deformations were determined. The data were evaluated by mathematical-statistical methods, and in this way it was established that the correlations between the individual characteristics and the amount of the added gluten may be characterized with the aid of regression curves of the second degree. The equations of the individual curves and the calculated correlation quotients are given as follows:

Total deformation	$T_G = 9.45 + 2.12G - 0.12G^2,$	r_{TG}	$= 0.942$
Elastic deformation	$E_G = 6.33 + 0.69G - 0.025G^2,$	r_{EG}	$= 0.756$
Plastic deformation	$P_G = 3.13 + 1.42G - 0.09G^2,$	r_{PG}	$= 0.949$
Relative elasticity	$RE_G = 64.7 - 4.02G + 0.26G^2,$	r_{REG}	$= 0.825$
Volume	$V_G = 1021 + 105G - 7\ G^2$	r_{VG}	$= 0.957$

where G is the amount in per cent of the dry gluten used for preparing the dough, calculated to the amount of flour.

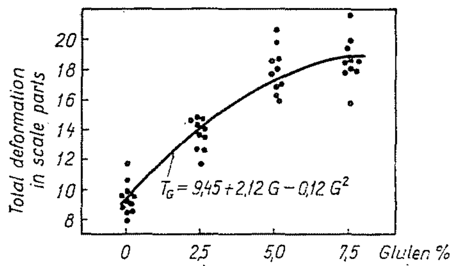

Fig. 1

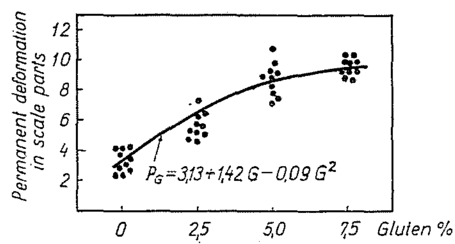

Fig. 2

The results are graphically shown in Figs. 1, 2, 3, 4 and 5. Moreover, the values of the apparent modulus of elasticity and apparent plastic viscosity have also been calculated. These values are contained in Table 1.

Table 1

Elasticity and plasticity of breads prepared with gluten

Series	Added gluten, %							
	0.0		2.5		5.0		7.5	
	E_{app} g/cm²	η_{plapp} 10^5 poise	E_{app} g/cm²	η_{plapp} 10^5 poise	E_{app} g/cm²	η_{plapp} 10^5 poise	E_{app} g/cm²	η_{plapp} 10^5 poise
1	2.39	0.281	0.99	0.118	0.86	0.058	1.57	0.072
2	2.96	0.361	1.04	0.115	0.86	0.058	0.77	0.060
3	1.48	0.305	1.15	0.137	0.77	0.045	0.95	0.058
4	2.26	0.265	1.22	0.127	0.70	0.059	0.59	0.049
5	1.32	0.216	1.04	0.130	1.07	0.059	0.82	0.054
6	2.48	0.505	0.91	0.153	0.98	0.088	0.77	0.056
7	1.92	0.436	0.98	0.128	1.20	0.081	1.07	0.060
8	2.56	0.517	1.71	0.190	1.10	0.061	1.10	0.059
9	2.56	0.274	2.26	0.111	0.93	0.077	0.95	0.054
10	2.13	0.312	2.08	0.118	1.07	0.074	0.95	0.054

On the basis of the test results it can be stated that the changes due to the increase of the gluten content may be characterized by regression curves of the second degree of similar character. The significance of the correlation ratios is high in every case. The total, plastic and elastic deformations increase with the amount of the added gluten, as shown in Figs. 1,

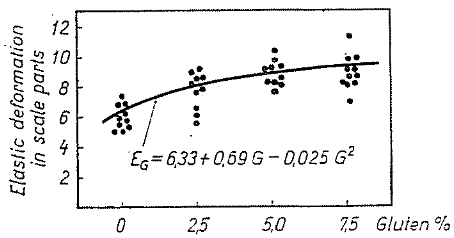

Fig. 3

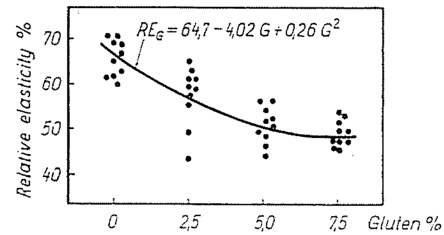

Fig. 4

2 and 3. The degree of the increase of the plastic deformation exceeds the increase observed in the case of elastic deformation, and the relative elasticity correspondingly decreases (Fig. 4). This result is at first striking because in developing the elastic properties of the crumb the gluten proteins play the leading role, and it could be expected that the increase of the gluten content of the crumb is connected with an improvement of the elastic properties, e.g. of the relative elasticity. The contradiction can be explained, however,

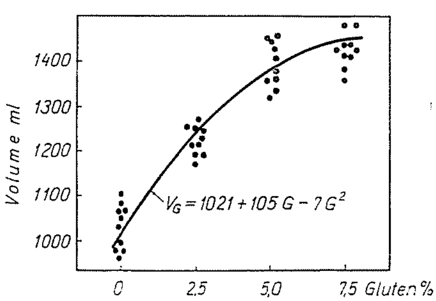

Fig. 5

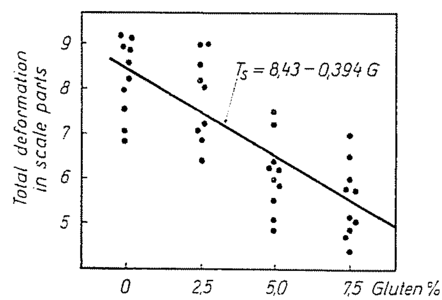

Fig. 6

by taking into account the fact that, due to the addition of gluten, a volume increase of high degree occurs (Fig. 5). The larger volume means a smaller pore-wall thickness and both factors cause an increase of deformation. Moreover, the plastic deformation being a function of time too, in the case of this deformation the effect of the volume increase appears in a higher degree.

In order to eliminate the effect of the volume-change, a series of experiments was carried out, and the volumes of breads containing gluten in different amounts were adjusted to the same value. This could be attained by suitably modifying the addition of yeast and the conditions of raising. The rheological properties of the crumb of breads having approximately identical volumes and prepared with added gluten were investigated in the same way

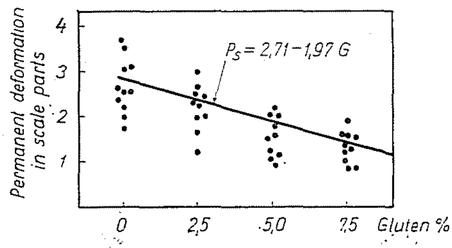

Fig. 7

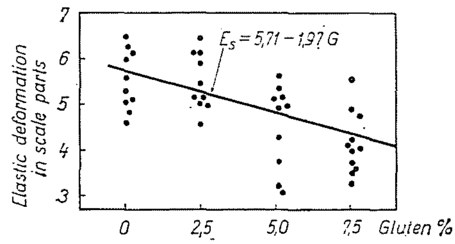

Fig. 8

as previously described. The total, plastic, elastic deformations, and the relative elasticity were measured. By evaluating the data with mathematical-statistical methods, the following regression equations and correlations coefficients, respectively, were obtained:

$$\begin{array}{llll} \text{Total deformation} & T_S = 8.43 - 0.394\,G & r_{TS} & = -0.76 \\ \text{Elastic deformation} & E_S = 5.71 - 0.197G & r_{ES} & = -0.58 \\ \text{Plastic deformation} & P_S = 2.71 - 0.197G & r_{PS} & = -0.76 \\ \text{Relative elasticity} & RE_S = 68.02 + 1.17G & r_{RES} & = 0.61 \end{array}$$

where G is the amount in per cents of the dry gluten added to the dough, calculated to the amount of flour.

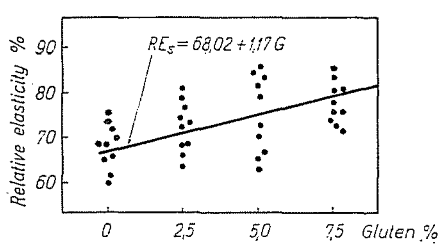

Fig. 9

The data as well as the regression lines are shown in Figs. 6, 7, 8 and 9 while the values of the apparent modulus of elasticity and apparent plastic viscosity are given in Table 2.

The correctness of the assumptions described before is justified by both the diagrams and the tables. In the case of the breads having nearly identical volumes, the degree of the total deformation decreases and the relative

Table 2

Elasticity and plasticity of the crumb of breads prepared with gluten and having practically identical volumes

Series	Added gluten, %							
	0.0		2.5		5.0		7.5	
	E_{app} g/cm²	η_{plapp} 10^5 poise	E_{app} g/cm²	η_{plapp} 10^5 poise	E_{app} g/cm²	η_{plapp} 10^5 poise	E_{app} g/cm²	η_{plapp} 10^5 poise
1	2.15	0.645	2.08	0.505	4.35	0.950	3.35	1.218
2	3.08	0.550	2.63	0.924	2.45	0.910	7.40	2.040
3	3.34	0.950	3.08	1.380	5.95	0.995	4.15	1.170
4	1.83	0.462	2.00	0.632	3.50	1.040	3.45	1.050
5	2.00	0.376	2.85	0.721	2.75	0.641	5.59	1.320
6	3.08	0.358	2.15	0.383	2.45	1.445	6.25	1.623
7	2.60	0.695	2.80	0.665	3.20	1.960	3.35	2.250
8	2.08	0.365	1.83	0.462	2.96	1.360	4.35	0.960
9	2.73	0.312	2.96	0.444	2.85	1.680	4.82	1.460
10	2.45	0.487	2.96	0.572	2.85	1.218	4.82	2.415

elasticity increases with the increase of the gluten content. The two changes show that the mechanical strength and the elasticity of the crumb skeleton increase under the influence of the gluten addition. The fact, that the elastic properties of the crumb of bread are ensured primarily by the denatured gluten proteins, is again supported by these observations.

Evaluation of publications I—V

1. The crumb of bread has both elastic and plastic properties. Consequently, for its rheological characterization, the knowledge of the compressibility, that is of the total deformation, is not sufficient because the knowledge of the ratio of the elastic and plastic deformations is needed as well. In our papers published elsewhere [10, 11] it has been proved that the phenomenon of retarded elasticity is also shown by the crumb of bread. The rheological properties of the crumb of bread can be readily approximated by a model consisting of five elements (2 Hooke elements, 2 Newton elements, and 1 plastic element) shown in Fig. 10. A characteristic curve obtained by plotting the deformation against time is shown in Fig. 11.

2. For characterizing numerically the physical properties of the crumb of bread, besides the total, elastic and plastic deformations, the apparent modulus of elasticity and apparent plastic viscosity may be used as well.

The calculation may be carried out on the basis of the following equations:

$$E_{app} = \frac{P}{2r\pi h_e} \cdot \frac{1}{h_e} \quad \text{and}$$

$$\eta_{plapp} = \frac{P}{2r\pi \cdot 0.89\, h_l} \cdot \frac{1}{h_p} \cdot t$$

where E_{app} = apparent modulus of elasticity in g/mm²
r = radius of the pressing body of hemispheroidal form in mons
h_e = elastic deformation in mms
l = height of the tested crumb sample in mms
η_{plapp} = apparent plastic viscosity in 10^5 poises
h_t = total deformation in mms
h_p = plastic deformation in mms
t = time of action of the deforming strength in sec.

3. The rheological properties of the crumb are changed by the additives used in the baking industry. The change of the rheological properties is the result on the one hand, of the volume increase and decrease, respectively,

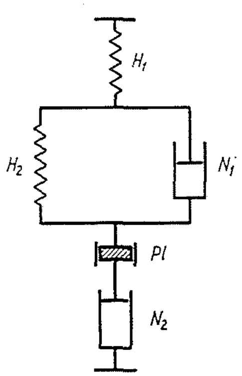

Fig. 10

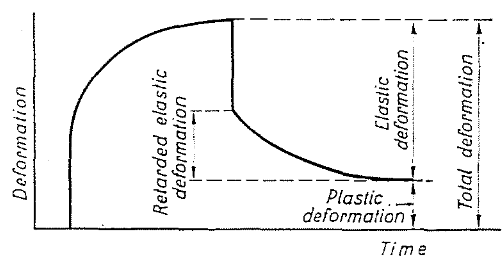

Fig. 11

and on the other hand it is the result of the changes occurring in the structure of the skeleton forming the crumb wall.

Most of the additive agents tested (potatoes, milks of various fat contents, fats, surface-active agents, gluten) increase the degree of the total and plastic deformations; an exception is presented by skimmed milk and gluten. In the case of fullcream milk, the trend is different, due to the effect of fat and lipoid contents. A definite increase of the elastic deformation can be observed only by adding gluten, while in the case of adding other additives decrease or increase of a smaller degree can be observed, the relative degree of the latter usually remaining behind the increase of the plastic deformation. The relative elasticity of the crumb of bread decreases, with the exception of gluten addition, whereby in every case it is shown that in developing the elastic properties of the crumb the leading role is played by the gluten proteins.

4. It is a difficult task to investigate separately the volume increase and the changes of the crumb structure. If the volume increase is of a small degree then its effect may be taken into account by dividing the measured deformations by the quotient of the average pore-wall thicknesses of the original products and of the products of increased volume. The quotient may be calculated with the aid of the following equation:

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

where f = mean pore-wall, cross-section in mm^2 of the crumb of control breads

f_1 = mean pore-wall cross-section in mm^2 of the breads with increased volume

P = pore volume (%)

V_N = volume increase (%).

The deduction of this approximate calculation was published in a previous paper [8].

If the volume increase is high, then satisfactory results can be obtained only by testing the crumbs of breads having nearly identical volumes as a consequence of choosing suitably the conditions of making the breads.

Summary

The rheological properties of the crumb of breads prepared with the addition of different quantities of dried native gluten 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 was established that the degree of the total, plastic and elastic deformation increases when increasing the quantity of the gluten added. The relative elasticity decreases. This result is at first striking because in developing the elastic properties of bread-crumb the gluten proteins play the leading role. The contradiction can be explained, however by taking into account the fact, that due to the addition of gluten a volume increase of high degree occurs.

The total deformation of the crumb of breads prepared with added gluten and having approximately identical volumes decrease with the quantity of gluten, and an increase of relative elasticity occurs.

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