Vacuum Expansion of Mechanically Developed Doughs at Proof Temperature: Effect of Shortening[1]

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ABSTRACT

Cereal Chem. 58(3):182–186

A technique for the controlled vacuum expansion of doughs made by the Chorleywood Bread Process enabled effects of shortening usually observed only during the early stages of baking to be demonstrated at a proof temperature below the slip point of the shortening. Like doughs in the oven, vacuum-raised doughs were increased in size by the presence of shortening but were not significantly increased by the presence of vegetable oil. Doughs containing added fat at a level of 0.7% and made from flours stored for five years at ambient temperatures expanded significantly less under vacuum than did similar doughs made with control flours kept at −20° C in an inert atmosphere, except that in the case of the weak flour the difference did not reach significance. The interrelationships between the shortening and other dough components that lead to increased loaf volume must be largely established by the end of the final proof stage of dough making.

Although shortening (added fat) is needed for the production of good bread by the Chorleywood Bread Process (CBP), as reported by Chamberlain et al (1965), rheological tests on doughs with and without shortening do not show differences consistent with its improving effects on loaf volume. Any changes in dough properties were variable, according to the type of fat or flour used, in tests with the farinograph (Moore and Herman 1942) and extensigraph (Merritt and Bailey 1945). With the Chopin alveograph (Jelaca and Dodds 1969), shortening slightly increased the softness of the dough at both 25 and 50° C. Although added fat and oxidants had opposite effects on dough properties, both increased loaf volume. Shortening had a negligible effect on gas production and gas retention at proof temperature and at 54° C (Fisher 1969), and doughs with and without added fat therefore proofed to the same height in the same time. The difference became apparent only when they were placed in the oven (Bell et al 1977, Fisher 1969).

The assumption had always been made that fat enabled the dough to retain fermentation gases better during the initial rapid expansion in the oven. Daniels and Fisher (1976) were able to prove that carbon dioxide begins to escape later from doughs with shortening than in those without but release then continues at similar rates in the two kinds of dough.

Because the effects of shortening only show in the oven, they have sometimes been assumed to be the direct result of heating the dough above proof temperature, perhaps involving the melting of solid fat. To find whether heat was essential to the action of shortening, the rapid expansion that normally takes place in the oven was simulated by applying a vacuum to doughs with and without shortening that were held at proof temperature. The idea of using vacuum originated from work on gluten by Bungenberg de Jong (1956) and has also been adopted for doughs (MacRitchie 1976). Our experiments compared the effects of shortening, of a liquid triglyceride, and of flour type and condition both on dough expansion at proof temperature and on bread volume.

MATERIALS AND METHODS

Flours

Samples of three flours of differing baking strengths, designated "weak," "medium," and "strong" (Bell et al 1979a), were canned shortly after milling and held at −20° C in an inert atmosphere to act as controls for samples of the same flours stored at ambient temperatures (mean, about 12° C). The flours used in this work, taken after storage for five years at ambient temperatures, had obviously deteriorated in baking quality, and the controls had not.

Fats

A commercial shortening (Van den Berghs and Jurgens Ltd., Burgess Hill, W. Sussex; slip point 43° C) was added to doughs at levels of 0, 0.7, and 2.1% w/w flour. Glyceryl trioleate (BDH Chemicals Ltd., Poole, Dorset) was added at the 0.7% level, where "oil" was indicated.

Expansion Tubes

Glass test tubes (about 25 cm × 5 cm ID) were made with ST 55/44 joints. The walls were silanized to prevent the dough from sticking, and the ground glass joints were sealed with the shortening. The vertically mounted tubes were individually calibrated by measuring the height of the meniscus with a cathetometer after 12 successive 25-ml additions of water.

Doughs

CBP doughs (Axford et al 1963) for vacuum expansion were mixed singly from 28 g of flour (Bell and Fisher 1977, Bell et al 1979b), one tenth the weight used to make 454-g CBP doughs from the same flours for baking bread (Bell et al 1979a).

The doughs were molded in a commercial shaper (Henry Simon Ltd., Stockport, Cheshire) modified to handle a smaller dough. Each dough was then rested for 10 min at 27° C, remolded, and dropped into an expansion tube without touching the ground glass joint, pressed to the shape of the base to avoid trapping pockets of air, and flattened at the top. The tube was closed with a stopper supporting a plug of moist cotton wool to prevent formation of a skin of dried dough and was kept in a water bath at 38 ± 1° C for 40 min to proof the dough.

Vacuum Expansion

A tube containing a proofed dough was transferred to a glass water bath maintained at 38 ± 1° C. The heights of the bottom and top of the dough were measured with a cathetometer before the vacuum was applied. An 18-L reservoir was included in the vacuum line to achieve a slow, steady rate of evacuation, which was controlled by manual adjustments of a calibrated needle valve. The optimum rate of pressure reduction (Fig. 1), determined empirically for doughs made with medium control flour without shortening, was used throughout. Dough height and pressure were measured with the cathetometer and a mercury manometer at 1-min intervals throughout expansion at 38° C. Tests on each kind of dough were carried out in triplicate.

Calculation of Results

Corrections for minor variations in dough weight and tube dimensions were applied but did not affect the statistical significance of differences between the results or their interpretation. The effects of including or omitting shortening or oil were determined by testing pairs of variants on three separate

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[1] Portions presented at a symposium, Theory and Application of Lipid-Related Materials in Breadmaking: Today and Tomorrow (Not Yesterday), at the 64th Annual Meeting, Washington, DC, October 1979.

days. Because no significant differences were found between the heights of similar doughs expanded on different days, later experiments were planned with a randomized block design spanning several days. Results of the experiments were examined statistically by two-way and three-way analysis, using Tukey's multicomparison test (Scheffé 1959).

RESULTS

Doughs With and Without Shortening

The relationships between pressure and dough height during the expansion of control flour doughs made with weak, medium, and strong flours with and without added fat are shown in Fig. 2. Doughs other than those made from the weak flour without fat began to rise as soon as pressure was reduced. The course of their subsequent expansion depended on the type of flour and whether shortening was included in the dough. When the vacuum reached approximately the vapor pressure of water, all doughs started to rise rapidly to a maximum height, which was maintained for 20–120 sec before they began to shrink. This led to the sharp final peaks on the graphs (Fig. 2), for which the gain in height was similar with all doughs regardless of flour type or the addition of shortening. The dough heights reported in the tables and in Fig. 3 were recorded at the top of this peak.

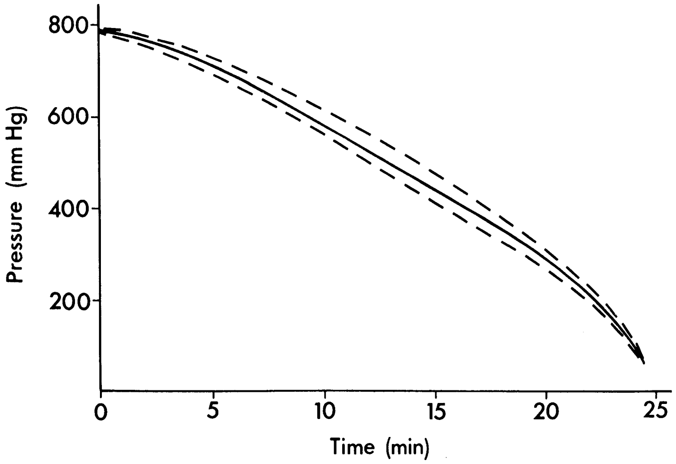

Fig. 1. Rate of pressure reduction. Dashed lines indicate experimental deviation from the planned rate.

Shortening (0.7% w/w flour) increased the mean height of expanded doughs made with all three control flours (Table I). The differences between doughs with and without shortening were highly significant ($P < 0.001$). Fully expanded dough heights also increased with increasing flour strength ($P < 0.001$). No significant interaction was found between differences due to shortening and those due to flour type.

Direct comparisons between the volumes of loaves and of vacuum-expanded doughs were not possible. Dough volumes could not be measured directly while the tubes were evacuated, due to the irregular shape of the dough top. Estimates for the control flour doughs were obtained assuming a hemispherical top. Dough or loaf volume/dough weight ratios of doughs made with and without shortening from the three flours after expansion by vacuum (45.4-g doughs) or by baking (454-g doughs) are shown in Table II. Differences in this ratio caused by addition of shortening or by differences in flour type are similar, but not identical, for the two methods of dough expansion. The specific volumes of CBP loaves baked from 45.4 and 454 g of dough were previously also found to differ slightly,[2] but the present differences are more likely to be the result of the different methods of expanding the doughs.

Doughs with Glyceryl Trioleate

Addition of 0.7% oil was ineffective at improving loaf volume (Bell and Fisher 1977) and also failed to increase the peak height of vacuum-expanded doughs significantly, compared with similar doughs without shortening or oil (Table III). Two-way statistical analysis showed that differences between doughs containing shortening and those containing oil and between similar doughs made from different flours were all highly significant ($P < 0.001$). Differences between doughs containing oil and those without added fat were not significant.

Effect of Flour Storage

The poor loaf volumes obtained with three ambient-stored flours were only slightly increased by adding 0.7% fat, and up to three

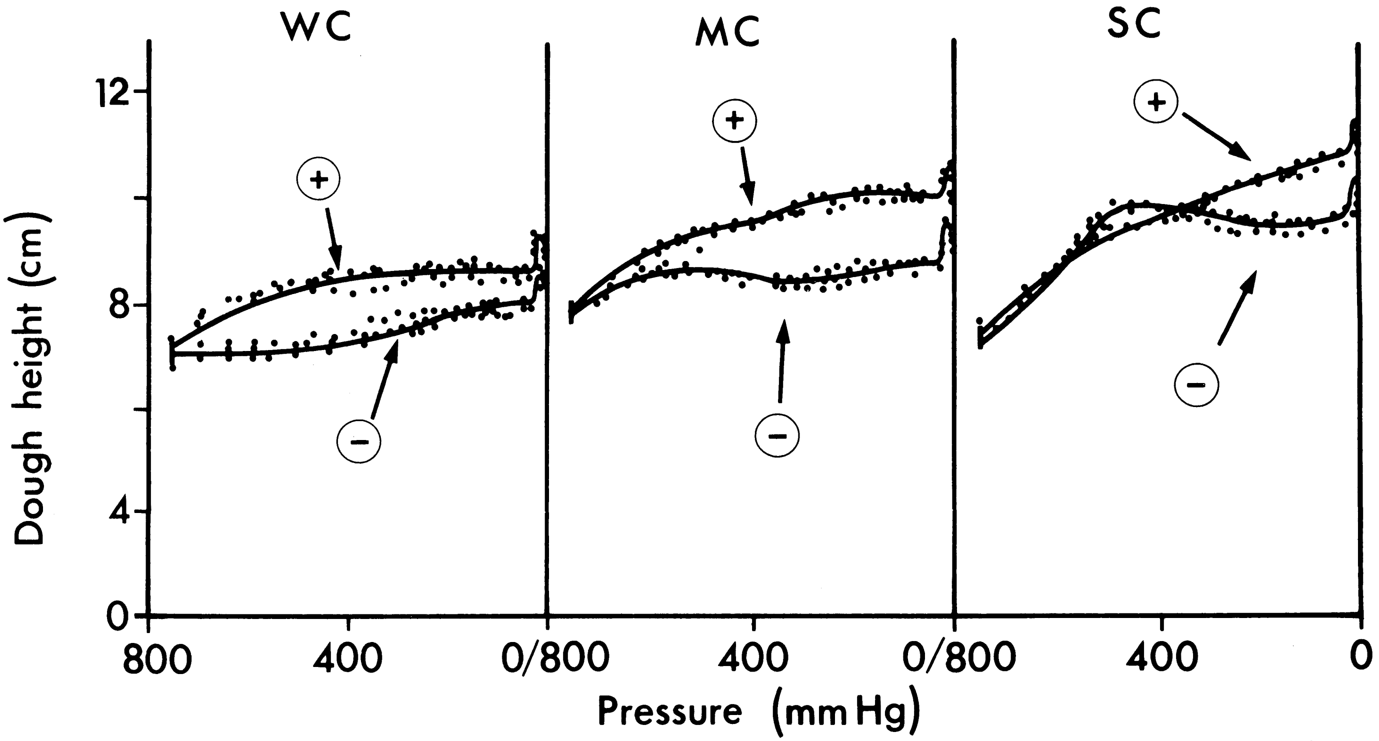

Fig. 2. Course of expansion of doughs prepared from control flours with or without shortening, using the rate of pressure reduction shown in Fig. 1.⊕= with shortening (0.7% w/w flour),⊖= without shortening. Flours: **WC** = weak control, **MC** = medium control, **SC** = strong control.

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[2] Unpublished work.

times this level was needed to produce commercially acceptable bread (Chamberlain et al 1980). With fresh flours, higher concentrations than the recommended 0.7% did not appreciably increase the loaf volume obtained by the CBP. Figure 3 shows the results of the vacuum expansion of control and ambient-stored flour doughs without shortening or with shortening at levels of 0.7 and 2.1% w/w flour. Three-way statistical analysis showed that the following differences were significant: the increases in expanded dough height due to fat addition ($P < 0.001$), those between control and stored flour doughs ($P < 0.01$) and between flour types ($P < 0.001$), and individual differences between 0.7 and 2.1% shortening (P either < 0.01 or < 0.001). No significant interaction was found between the effects of shortening and flour type, but that between the effects of shortening and storage was highly significant ($P < 0.001$).

The peak heights of doughs made from stored flour and containing added fat (0.7%) were all slightly less than those of the corresponding control flour doughs (weak, −0.15 cm; medium, −0.60 cm; strong, −0.60 cm). The differences in milliliters between loaf volumes using the same flours (Table IV) were: weak, −112; medium, −305; and strong, −363. The weak stored flour dough with extra shortening (2.1%) expanded more than, the medium one equally to, and the strong one less than the corresponding control flour doughs with 0.7% shortening. These results were all paralleled by the variations in the volumes of loaves baked from such doughs (Table IV). The one exception to the general relationship between vacuum expansion and baking was that control flour doughs with 2.1% shortening expanded more under vacuum than did those with 0.7% shortening, whereas their expansion in the oven would have been similar.[3] CBP fat addition curves for these control flours, plotted using the loaf volume/fat addition data of Chamberlain et al 1980, showed that the loaf volume had reached a plateau for the weak and medium flours at 0.7% fat (2 lb/sack) and had virtually done so for the strong flour at this fat level.

TABLE I
Peak Heights[a] of Control Flour Doughs With and Without Shortening

	Flour Type		
Dough	**Weak**	**Medium**	**Strong**
With 0.7% shortening[b]	9.3	10.3	11.2
Without shortening	8.7	9.4	10.2

[a] Mean of triplicate values (cm); standard error of residuals = 0.014.
[b] Percent (w/w) flour.

TABLE II
Specific Volumes[a] of Control Flour Doughs With and Without Shortening Expanded by Heat or Vacuum

	Flour Type		
Dough	**Weak**	**Medium**	**Strong**
Baked			
With shortening[b]	3.1	3.4	3.6
Without shortening	2.6	2.6	2.9
Vacuum-expanded[c]			
With shortening[b]	3.2	3.6	4.0
Without shortening	3.0	3.2	3.6

[a] Specific volume, ml/g = volume of baked loaf/original dough weight or volume of expanded dough/original dough weight.
[b] 0.7% w/w flour.
[c] Dough volumes estimated assuming a hemispherical top.

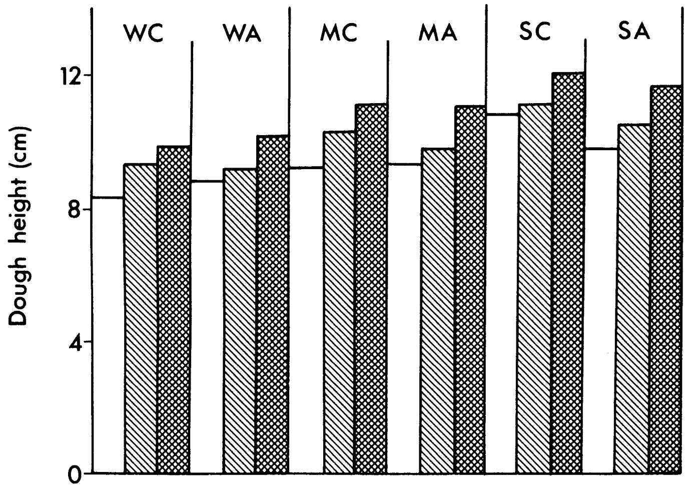

Fig. 3. Effect of increasing shortening addition on the peak heights of control and ambient-stored flour doughs expanded by vacuum, using the rate of pressure reduction shown in Fig. 1. Shortening levels (w/w flour): □ = 0%, ▨ = 0.7%, ▩ = 2.1%. Flours: **WC** = weak control, **WA** = weak ambient, **MC** = medium control, **MA** = medium ambient, **SC** = strong control, **SA** = strong ambient.

Expansion of Doughs Containing Different Levels of Carbon Dioxide

Vacuum expansion of doughs proofed for 40 and 5 min and of unyeasted doughs (Fig. 4) showed that expansion was delayed when less carbon dioxide was available than in the dough proofed for 40 min. Doughs without yeast expanded to almost the same height as doughs with yeast once sufficient water vapor pressure had built up. The difference between doughs with and without shortening was approximately halved when they were proofed for only 5 min instead of 40 min, and no difference was found between unyeasted doughs with and without shortening.

DISCUSSION

The Influence of Shortening on Dough Expansion

These experiments demonstrated effects of shortening on dough properties not detected by the usual rheological methods. Such methods often use unyeasted doughs, and even when yeast is included, the doughs are usually unproofed. A recent test based on the expansion of fermenting doughs (Hoseney et al 1979) was not examined for its ability to demonstrate the effects of shortening or

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[3] Chamberlain et al, private communication.

TABLE III
Peak Heights[a] of Control Flour Doughs Containing Shortening or Oil

	Flour Type		
Dough	**Weak**	**Medium**	**Strong**
Containing			
Shortening[b]	9.4	10.7	11.8
Oil[b]	8.6	9.7	11.0
Containing			
Oil[b]	8.9	9.7	10.8
No added fat	8.7	9.5	10.7

[a] Mean of triplicate values (cm); standard errors of residuals = 0.020 (shortening/oil) and 0.017 (oil/no added fat).
[b] 0.7% w/w flour.

TABLE IV
Volumes (ml) of Chorleywood Bread Process (CBP) Loaves Baked Using 280 g of Control and Ambient-Stored Flours

	Flour Type		
Dough	**Weak**	**Medium**	**Strong**
Control flour			
Without shortening[a]	1,201	1,199	1,306
With 0.7% shortening[b]	1,422	1,561	1,666
Ambient-stored flour			
Without shortening[b]	1,212	1,161	1,187
With shortening			
0.7%[b]	1,310	1,256	1,303
2.1%[a]	1,466	1,540	1,521

[a] Single loaf volumes obtained during determination of the fat requirements of four and a half year old flours (Chamberlain et al 1980).
[b] Mean volumes of four loaves from each of three dough mixings, obtained during routine CBP testing of flours (Bell et al 1979a).

of flour storage. In the present work, 454-g doughs proofed to a constant height (10 cm) in the same time, irrespective of flour type or condition and of whether shortening was included or omitted.

A controlled reduction in pressure was chosen for expanding doughs by vacuum, rather than the more rapid rates used by previous workers (Bungenberg de Jong 1956, MacRitchie 1976), because doughs without shortening subjected to a rapid pressure reduction were found to expand initially and then to collapse suddenly. Subsequent recovery appeared to be restricted by collapse or breakdown of internal structures. The present technique allowed doughs without added fat to expand to their maximum potential volume at an approximately similar rate to the expansion during baking. Because doughs without shortening do not collapse in the oven, this appeared to be a more realistic approach.

The melting of solid fat after doughs are placed in the oven cannot be involved in the effect of shortening on gas retention; this has been demonstrated by expanding the dough without raising its temperature above that of proof. The interactions between shortening and other dough components must largely have been established by the end of the final proof stage of dough making.

The Relative Importance of Carbon Dioxide and Water Vapor

A dough placed in the oven heats up gradually. The temperature of the outside approaches the boiling point of water by the time the loaf sets, and the temperature of the inner crumb of a 1-lb loaf takes about 20 min to reach 100° C (Elton and Fisher 1966). Thus in the early stages of baking, the evolution of carbon dioxide from the outside of the dough coincides with the loss of steam from near the crust. During vacuum expansion, the losses of carbon dioxide and water vapor are separated to some extent. Differences in final expanded dough height were largely determined by the expansion before the rapid evaporation of water (Fig. 2), suggesting that differences in the retention of carbon dioxide rather than of water vapor were responsible for differences between doughs made with different flours and between those from the same flour with and without fat. This conclusion was supported by the similar size of vacuum-expanded doughs with and without shortening when yeast was omitted and the expansion was almost entirely due to water vapor pressure (Fig. 4).

Effect of Dough Properties

The shape of most of the curves in Fig. 2 could be explained by an improvement in the gas retention of the expanding dough by shortening, but strong flour doughs containing fat expanded less in the early stages than did similar doughs without added fat. A change in the viscoelastic properties of the strong flour dough must have occurred as a result of fat addition, and similar changes can therefore not be excluded in doughs made from other flours. The properties of gluten may be impaired during flour storage at ambient temperatures (Barton-Wright 1938, Fisher et al 1937), and unsaturated fatty acids released by lipolytic action are probably largely responsible (Bell et al 1979a, 1979b; Kosmin 1935). The observed statistical interaction between the effects of shortening and of storage on vacuum expansion and the increased fat requirements of stored flours may well both be related to the action of unsaturated fatty acids on gluten. Other inherent differences between flours may also exert an influence, however (Bell et al 1979a, 1979b).

Differences Between Vacuum Expansion and Baking

Obvious differences exist between vacuum expansion and baking. Amounts of carbon dioxide in the expanding doughs are different because fermentation continues at a steady rate throughout vacuum expansion, whereas in the oven it increases rapidly at first as the temperature rises, then ceases when the yeast is killed. Moreover, in the oven, proteins are denatured, starch becomes partially gelatinized, water is lost early in the expansion, a crust forms, and the loaf sets. During vacuum expansion, however, dough constituents are comparatively little changed. In addition, pressure gradients across gas cell walls may well have differed in the two methods of expansion, but no obvious method for their measurement appeared to be available. We cannot say, therefore, whether the slight differences in the expansions of doughs in the oven and by vacuum (Table II) were simply from a combination of these factors or whether heat has some secondary influence on the effect of shortening in the dough.

Expansion of doughs by vacuum using the present method does not appear to offer advantages over baking tests for routine assessment of flours. Baking tests are more reliable and easier in practice. The vacuum expansion technique would, however, be of value to study the effect of fat or other additives at different stages of dough development.

CONCLUSIONS

Increased expansion due to shortening has been demonstrated in dough at a temperature 4–5°C below the slip point of the shortening used in its preparation, whereas an oil failed to have this effect. These results suggest that although a proportion of the added fat is required to remain solid during mixing, and perhaps during proof, the melting of the solid fat during the comparatively rapid expansion of a dough when it enters the oven is not involved in the beneficial effect of fat on loaf volume. Some of the effects of storage deterioration and of differences between flour types were also demonstrated by vacuum expansion. Differences between doughs with and without fat decreased when proof time was reduced and were absent when yeast was omitted.

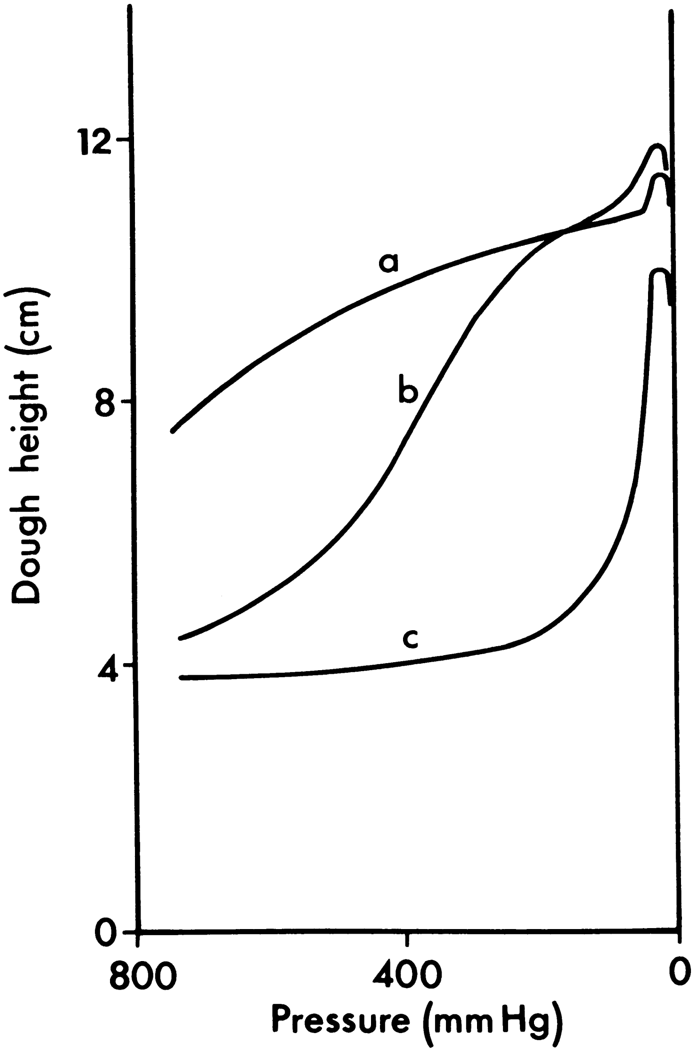

Fig. 4. Course of expansion of doughs made from strong control flour and containing shortening (0.7% w/w flour), using the rate of pressure reduction shown in Fig. 1. Curves: **a**, after 40-min proof; **b**, after 5-min proof; **c**, without yeast.

ACKNOWLEDGMENTS

This work forms part of a project sponsored by the U.K. Ministry of Agriculture, Fisheries and Food, to whom our thanks are due.

The help of P. Burgess, T. H. Collins, and R. Lawson is also gratefully acknowledged.

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[Received May 27, 1980. Accepted July 2, 1980]