

Gas Retention in Bread Dough During Baking¹

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ABSTRACT

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Gas retention in bread dough during baking was studied using pup loaves and an electric resistance oven. The amount of CO₂ released during the early stages of baking was small and constant. As the temperature was increased from 55 to 72°C, the rate of CO₂ release increased slightly. The major loss in gas-retaining ability of the bread dough appeared to start at 72°C. Doughs made from fractionated and reconstituted flours (gluten, starch, and water-soluble fractions) containing a preheated fraction and two unheated fractions showed that when starch was preheated

to above 70°C, the ability of the dough to retain gas was essentially lost. Similarly, doughs containing gluten or water solubles preheated to the same temperature retained gas. Therefore, the presence of gelatinized starch is apparently necessary for the change in gas retention of dough. A mechanism for changes in the gas-retaining ability of dough is proposed based on the dynamic rheological properties of dough during baking and the microscopic structure of baked bread.

Baking rheologically converts a viscoelastic dough into an elastic bread. Dough is a closed-celled foam that retains carbon dioxide during fermentation and the early stages of baking (Hoseney 1986), whereas baked bread is an open-celled sponge that is permeable to gas (Baker 1939).

Bloksma (1981) suggested that the transformation of a foam structure into a sponge structure with interconnected gas cells occurs because of starch gelatinization. He reasoned that starch gelatinization increases the dough viscosity, resulting in greater gas pressure within cells and greater tensile stress on the cell walls. The greater tensile stress initiates rupture of the walls and formation of holes through which excess pressure is released to the outside.

MacRitchie (1980) and Bloksma and Bushuk (1988) attributed the change in gas retention of dough during baking to starch gelatinization and protein coagulation. However, the importance of protein coagulation during baking has been questioned (Hoseney et al 1987). First, differential scanning calorimetry studies of gluten proteins have failed to show a denaturation peak (Eliasson and Hegg 1980, Arntfield and Murry 1981, Schofield et al 1984). Second, although Schofield and co-workers (1983, 1984) showed that thiol-disulfide interchange takes place during baking, this polymerization would not change the rheological properties of the system significantly (Hoseney et al 1987) because the proteins are much larger than the minimum required for entanglement (Graessley 1984). Third, Dreese et al (1988) observed only a small irreversible change in storage modulus (G') during heating of doughs made from 100% commercial gluten and water. The small increase in G' was shown to be caused by gelatinization of the residual starch in the gluten. From this, they concluded that the rheological properties of gluten are not affected by heating to 90°C.

The mechanisms that change the properties of bread dough during baking to affect gas retention have not been satisfactorily

determined. The objective of this study was to understand what triggers the transformation of a closed-celled dough foam to an open-celled bread sponge during baking.

MATERIALS AND METHODS

Flour

A commercial bread flour obtained from Ross Mills (Wichita, KS) was used. The flour contained 11.5% protein and 0.45% ash.

Measurement of CO₂ Release Rate

Dough was prepared as described in AACC method 10-10B (1983). Nonfat dry milk 4.0% (Galloway West, Fond du Lac, WI), 0.75% instant dry yeast (Gist-Brocades, Charlotte, NC), and 10 ppm KBrO₃ were added to the formula. Fermentation time was 180 min. The proofed bread dough was baked (213°C) in a conventional oven for 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, or 24 min. After baking for the desired time, the dough (bread) was taken from the oven and immediately transferred to a sealed box (resistance oven without the electrodes, He and Hoseney 1991). Unbaked dough was also tested. Nitrogen gas was allowed to flow through the box, and then to an infrared detector (Beckman model 865 infrared analyzer). The rate of CO₂ loss from the dough (bread) was measured as a function of time at room temperature (24°C).

It took 1.5 min to remove dough (bread) from the oven and start the measurement, and it took 2 min for the CO₂ in the air that was originally in the box to pass through the infrared detector. Therefore, to estimate the rate of CO₂ loss from the dough, a tangent line was drawn through the point at which N₂ passed through the dough (bread) for 2 min. This line was extrapolated back 3.5 min to obtain the rate of release when the dough (bread) was removed from the oven (Fig. 1.). Because of rapid cooling when dough was removed from the oven, the measured extrapolated rate of CO₂ loss was smaller than the rate of loss in the oven. Duplicate measurements were made for each baking time, and the standard deviation was calculated.

Temperature of Dough

Convection oven. A thermocouple was placed in the approximate center of the loaf and temperature recorded at various times.

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The loaf was baked on a stationary reel.

Electrical resistance oven. A thermocouple was placed about 10 mm from the bottom of the loaf (He and Hosoney 1991).

CO₂ Determination

Dough was baked in an electrical resistance oven (ERO). During baking, N₂ gas flowed over the dough and to an infrared CO₂ analyzer. Details of the procedure were given previously (He and Hosoney 1991).

Differential Scanning Calorimetry

Temperature for starch gelatinization in bread dough, made with a full formula except yeast, was determined by differential scanning calorimetry (using a Perkin-Elmer DSC-2). About 10 mg of mixed dough was placed in aluminum sample pans. The experiments were conducted at a scanning rate of 10°C/min.

Fractionation and Reconstitution

The fractionation and reconstitution procedure for flour-water dough is given in Figure 2. Flour-water doughs were heated in an electrical resistance oven (ERO) to 45, 60, 70, and 85°C. The heated doughs were immediately fractionated into a water-soluble fraction, gluten, and starch. Gluten could not be completely separated from starch when the dough was heated above 70°C. Therefore, to test the effect of heat on gluten baking quality, gluten was washed from unheated flour-water dough by the procedure shown in Figure 3. The fresh wet gluten was then heated in a small ERO (Creighton 1988) to 45, 55, 60, 65, 70, 80, 90, or 100°C. Each heated fraction (water-soluble, starch, or gluten) was separately lyophilized, ground, and reconstituted with the other two unheated fractions to obtain a flour with the same ratio of components as unfractionated flour.

Scanning Electron Microscopy of Dough

Preparation of mixed and fermented dough for scanning electron microscopy involved freezing a small portion of dough in liquid nitrogen, cyrofracturing, and freeze-drying with an Edwards tissue freeze-dryer at -50°C for 48 hr. The dried dough samples were mounted on specimen stubs with silver paste and

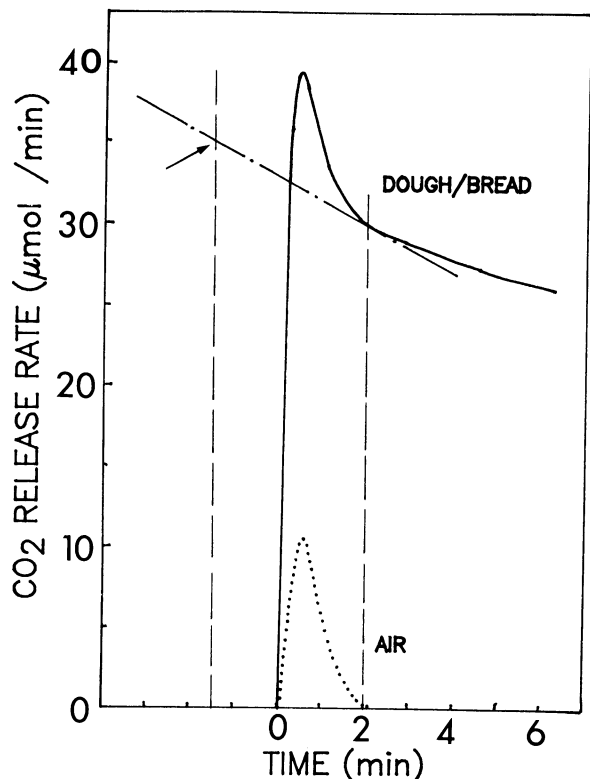


Fig. 1. A typical profile of carbon dioxide release from dough removed from a conventional oven after baking.

coated under vacuum with approximately 60 Å of carbon and then with about 100 Å of gold-palladium. Samples were viewed with an ELEC U-1 auto scan scanning electron microscope operating at an accelerating voltage of 5 kV. Images were photographed on Polaroid film, type 55.

RESULTS AND DISCUSSION

Transformation of Dough to Bread

When dough is baked in a conventional oven, heat is transported from the surface to the center mainly by the Watt principle

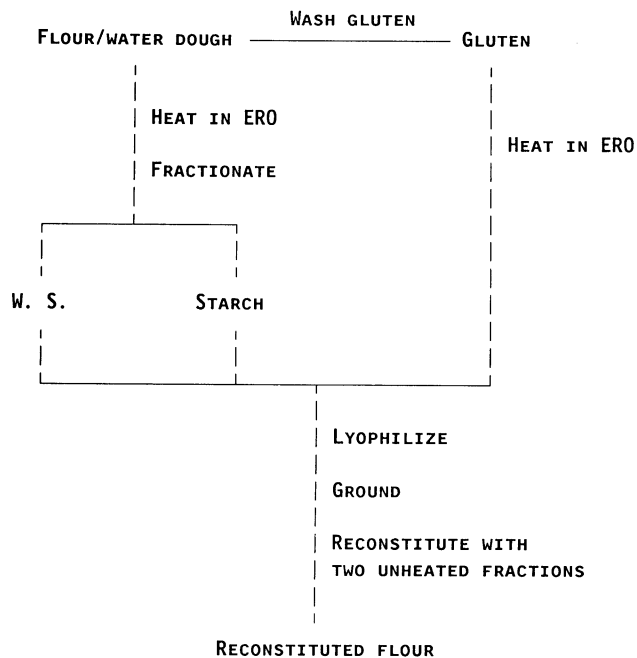


Fig. 2. Fractionation and reconstitution procedure. ERO = electrical resistance oven, W.S. = water-soluble fraction.

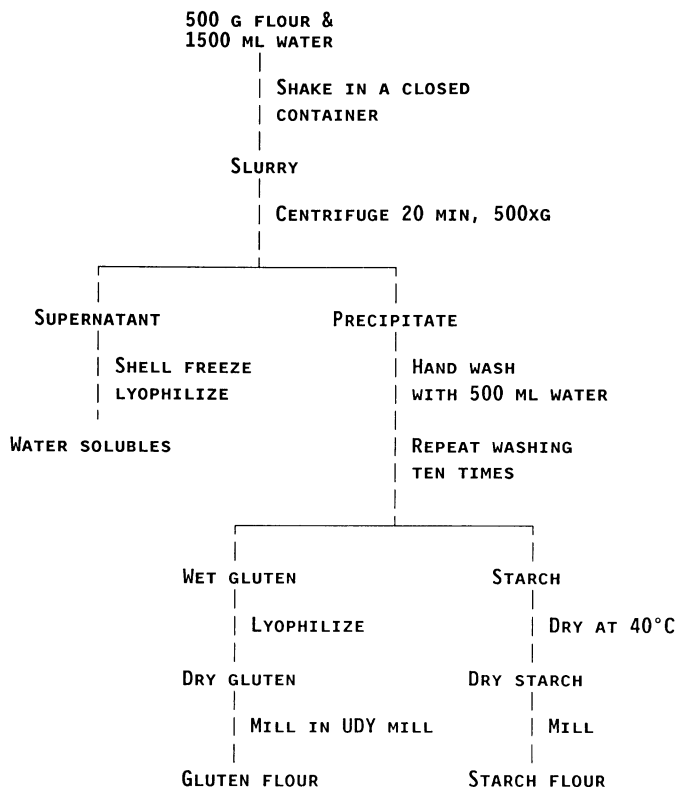


Fig. 3. Procedure for preparing gluten.

(Sluimer and Krist-Spit 1987). Therefore, heat-induced transformation of dough to bread occurs first at the surface and then progressively towards the center. Photographs of cross-sections of dough (bread) after baking 2, 5, 7, 8, and 24 min are shown in Figure 4. These are similar to those published by Sluimer and Krist-Spit (1987). After baking 2 min, only a thin layer at the surface of dough was transformed into bread (appearance). As baking proceeded, more dough was turned to bread. After 7 min of baking, only a small core of dough could be seen at the center of the loaf. After 8 min of baking, dough had disappeared, and the complete sample looked like bread crumb. However, if the bread at the center of the loaf was stretched by hand, it was extensible and much like dough. With further baking, the elasticity of the crumb increased and the extensibility decreased.

CO₂ Loss During Baking

When dough was baked in a conventional oven (213°C), the rate of CO₂ loss from dough (bread) changed with baking time (Fig. 5). Because the measurement was taken at room temperature (24°C), after dough (bread) had been out of the oven for 3.5 min, the rates plotted are only relative (see Methods). During the early stages of baking, the rate of CO₂ loss increased rapidly and reached a maximum after about 3 min of baking. After that, the rate decreased. No CO₂ was detectable from bread baked 13 min or longer. This data supports Baker's (1939) hypothesis that baked bread is permeable to gas.

The temperature in the center of the dough (bread) as it baked in the convection oven was 64°C at 7 min, 70°C at 8 min, 88°C at 10 min, and 94°C at 13 min of baking. Therefore, when dough (bread) reached 70°C, the doughy appearance disappeared, but the dough (bread) still retained part of the gas. However, it was difficult to accurately measure the temperatures at which the changes in dough appearance and gas retention took place during baking in a conventional oven. Therefore, the ERO (He and Hosenev 1991) was used to determine those temperatures.

Transformation Temperature

When dough reached the desired temperature in the ERO, heating was stopped, and the appearance, extensibility, and birefringence of starch in the dough near the thermocouple were examined. When dough was heated to 64°C, it had the appearance and properties of dough. When heated to 65°C, its appearance changed dramatically towards that of bread; however, it was extensible and easily compressed with gentle handling. Under polarized light, small starch granules were not birefringent, whereas most of the large starch granules were. When heated to 80°C, the dough looked like bread, its extensibility was greatly decreased, and the starch granules were no longer birefringent. Above 88°C, the loaf had little extensibility and its appearance was that of bread. By 95°C, it was bread with elasticity and

no extensibility. Therefore, the transformation from dough to bread is a slow and continuous process, which starts at 65°C.

A differential scanning calorimetric thermogram of bread dough with the full pup-loaf formula, except for yeast (Fig. 6), shows that starch gelatinization started at 64°C. It is possible that starch gelatinization and swelling are involved in the transformation of dough to bread.

Gas Release Temperature

To determine the temperature at which dough loses CO₂ during baking, the amount of CO₂ release from dough was measured in the ERO system (He and Hosenev 1991). The rate of CO₂ release during the early stages of baking was small and constant, apparently by way of gas diffusion (Fig. 7). As the temperature was increased from 55 to 72°C, the rate of CO₂ release increased slightly, and small peaks often occurred. At 72°C, the rate of

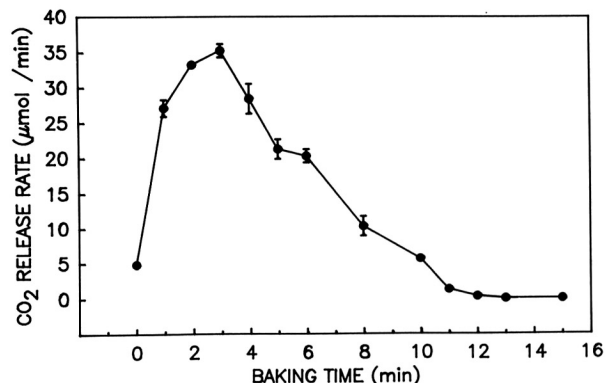


Fig. 5. Carbon dioxide release rates from dough and bread after various baking times.

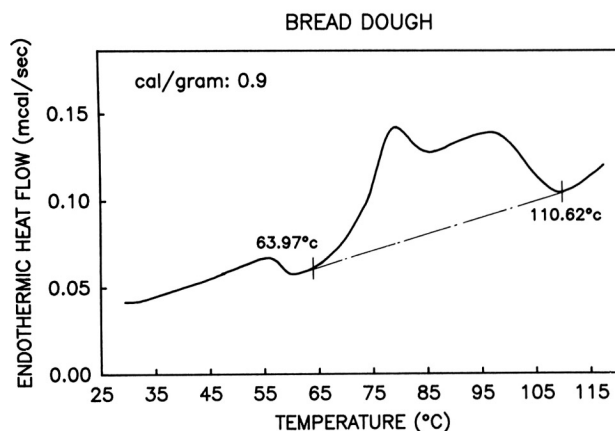


Fig. 6. Differential scanning calorimeter thermogram of bread dough without yeast.

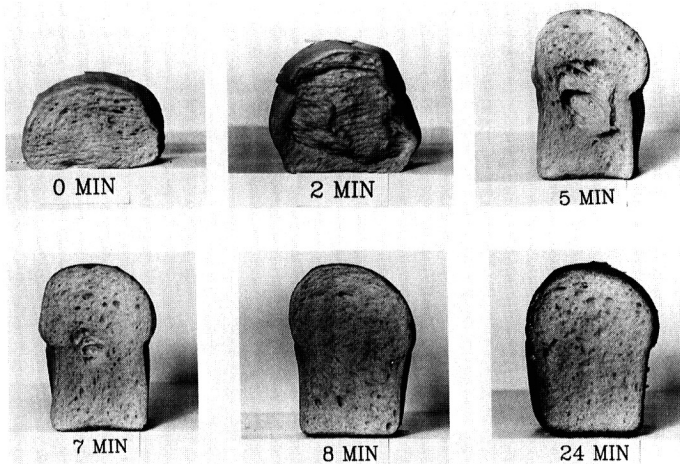


Fig. 4. Cross-sections of dough and bread before baking and after 2, 5, 7, 8, and 24 min baking.

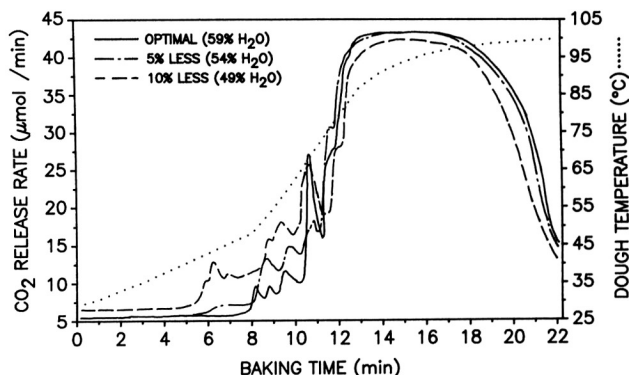


Fig. 7. Effect of water absorption on CO₂ release during baking.

CO₂ release increased rapidly, reaching a maximum at about 88°C. Thereafter, it remained relatively constant to about 97°C and then decreased sharply.

An increase in gas release below 72°C might be partially attributed to temperature, because the rate of CO₂ diffusion from dough would be expected to increase with temperature. On the other hand, when starch gelatinization and swelling take water from the gluten, the mobility of gluten decreases, and the viscosity of the dough increases. The higher viscosity and the resultant higher gas pressure in the cells also would be expected to increase the rate of CO₂ diffusion in dough. This effect can be demonstrated by decreasing baking water absorption. Figure 7 shows that decreases in water absorption from 59% to 54 or 49% led to a slight increase in the rate of CO₂ release but did not affect the temperature at which CO₂ was lost.

Fractionation and Reconstitution

To investigate factors affecting the gas release from dough at 72°C, preheated doughs were fractionated, and those fractions were then reconstituted with the other two unheated fractions. The amounts of CO₂ lost from doughs made from reconstituted flours during baking were measured to study the role of each flour component on gas retention.

Preheated Water Solubles

The rate of gas release from doughs made from reconstituted flour containing a water-soluble fraction preheated to 60 and 85°C is shown in Figure 8. The doughs containing preheated water-soluble fractions had essentially the same ability to retain gas as the doughs containing the unheated control fraction. This is consistent with the results of Hoseney et al (1969), who showed that boiling the water-soluble fraction does not destroy its positive effect on baking.

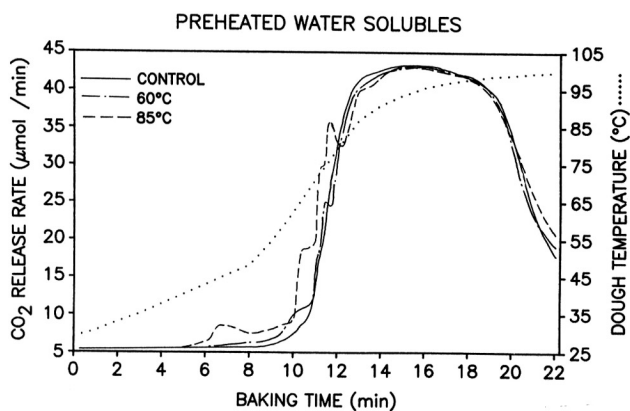


Fig. 8. Carbon dioxide release from reconstituted dough containing preheated water solubles.

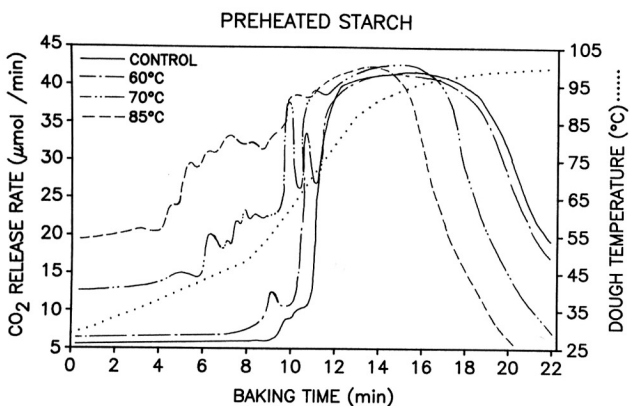


Fig. 9. Carbon dioxide release from reconstituted doughs containing preheated starch.

Preheated Starch

The ability of the dough made from reconstituted flour to retain gas did not significantly change when starch was preheated to 60°C (Fig. 9). However, when starch was preheated to 70°C, the reconstituted dough was stiff and resistant to extension, and its ability to retain gas was significantly decreased. When the reconstituted flour contained starch preheated to 85°C, the dough's extensibility was lost along with its ability to retain gas.

Preheated Gluten

The dough made from reconstituted flour containing gluten preheated to 45 and 60°C had essentially the same gas-retention properties as dough containing unheated gluten (Fig. 10). Therefore, the control in Figure 10 also represents the doughs containing gluten preheated to 45 and 60°C. Doughs made from reconstituted flours containing gluten preheated to temperatures between 65 and 80°C, retained CO₂. However, the rate of CO₂ release was higher than that from doughs containing the control unheated gluten. The gas retention ability of doughs made from reconstituted flours containing gluten preheated to 90°C or higher, decreased markedly.

Dreese et al (1988) showed that even well-washed gluten contains significant amounts of starch (about 8%). Aside from the effect of gelatinized starch, the rheological properties of gluten were not affected by heating to below 90°C (Dreese et al 1988). Therefore, the changes in gas retention ability of doughs made from reconstituted flours containing gluten preheated to below 90°C are assumed to be caused by the effects of gelatinized starch.

The question is, how does the gelatinized starch change the rheological properties of gluten? Measurements of the dynamic rheological properties of flour-water doughs during heating (Dreese et al 1988) showed that the storage modulus (G') decreased slowly as the dough temperature increased from 25 to 50°C, and then, after 55°C, began to increase rapidly, reaching a peak at approximately 75°C. The tangent decreased at the same temperature that the storage modulus increased. These authors also showed that the changes in G' and tangent from 55 to 75°C are directly proportional to the starch content of the dough. Presumably this starch gelatinization decreases the water available to the gluten. However, when doughs were prepared with decreased water, the G' value increased, but the tangent value was not affected. Therefore, they concluded that starch gelatinization affects dough rheology by a mechanism other than shifts in distribution of water. The increase in G' and decrease in tangent indicated an increased number of rheologically effective cross-links in the system; starch gelatinization provides the opportunity for increased entanglement and/or hydrogen bonding between gluten chains and partially solubilized starch from swollen granules (Hoseney et al 1987). Lindahl and Eliasson (1986) also reported that when wheat starch is gelatinized in the presence of gluten, G' increases. They suggested that this is a type of surface interaction between the starch granule and the gluten molecules.

The existence of starch-gluten interactions is also supported

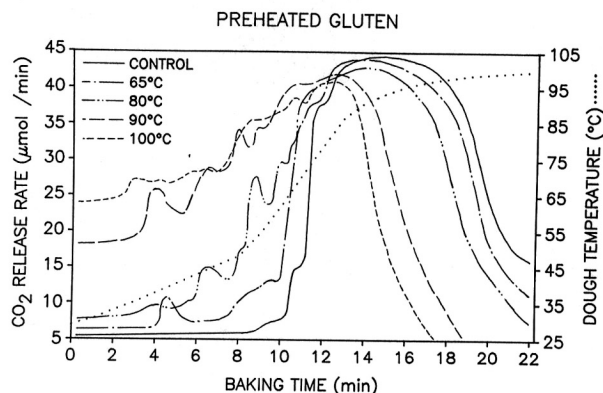


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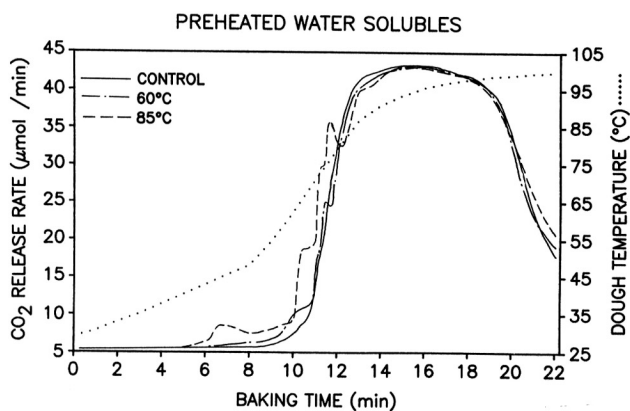


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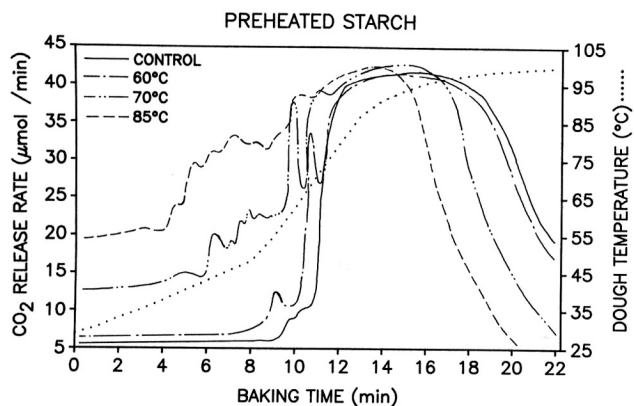


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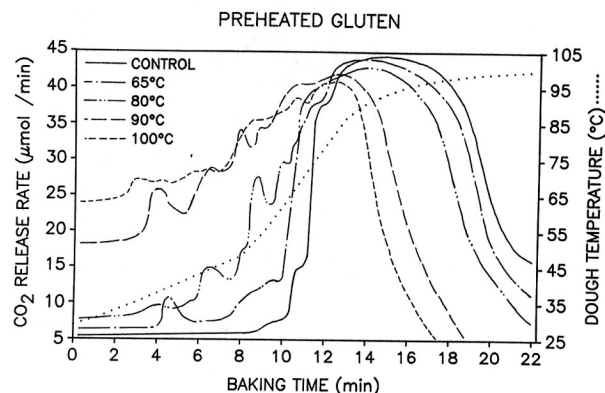


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