STUDIES OF WATER BINDING BY DIFFERENTIAL THERMAL ANALYSIS. III. BREAD STUDIES USING THE MELTING MODE[1]

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ABSTRACT

Differential thermal analysis melting thermogram results showed a significant decrease in bound-water content of wheat bread crumb with post-baking storage time. The rate of decrease was slowed down by including fat in the bread formula and by storing the bread at low temperatures. Baking absorption had a marked influence on bound-water content in bread; it increased with increasing water absorption. The rate of decrease of bound water during storage was slower in crumb baked at higher absorptions. Flour protein content and level of starch damage had no direct effect on bound-water content of fresh crumb or on changes during post-baking storage.

The first two articles of this series (1,2) dealt with differential thermal analysis (DTA) of water binding in dough. This article presents results on bread obtained with the melting mode of DTA. The binding of water in bread is relevant to the keeping quality or staling during post-baking storage (3,4).

MATERIALS AND METHODS

Bread

Loaves were baked by the "remix" experimental baking procedure described by Irvine and McMullan (5). The bread formula used is given in Table I. Modifications to this formula will be indicated in the relevant section of **Results and Discussion**. The baked loaves were individually sealed in polyethylene bags immediately after their volume was measured. Loaves were stored at room temperature (26° C) except in the case of the loaves used for the storage temperature study. For this study, loaves were stored at 26° C (room temperature), 4° C (refrigerator), and −20° C (deep freezer) for different periods of time. The loaves stored at 4° and −20° C were warmed to room temperature (enclosed in polyethylene bags) by exposing them to room temperature for 3 hr before thermal analysis.

For study of the effect of storage time on bound-water content of bread, flour from the Canadian hard red spring cultivar Pembina was used. For all other studies, the bread was baked from flour of the hard red spring cultivar Manitou.

For experiments at different dough moistures, loaves were baked at absorptions of 4% above and below the optimum absorption of the flour. Loaves were also baked from three different Manitou wheat flours of 9.9, 12.4, and 14.1% protein to examine the effect of protein content on changes in water binding in bread during storage.

For DTA, one loaf of each bake was used for each measurement. The loaf was sliced vertically into two pieces and approximately 25 mg of bread crumb was

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taken from the central region of the loaf as the experimental subsample. Immediately after sampling, the sliced loaf was repacked in polyethylene bags. The experimental subsample was inserted into the DTA sample tube, compressed with a glass rod, and weighed immediately before analysis.

Bound water in bread crumb was determined by the procedure used for dough (2). Each result was the average of three analyses. Moisture content of the crumb was calculated from the weight loss on heating overnight at 105°C.

RESULTS AND DISCUSSION

Effect of Post-Baking Storage Time

With increasing post-baking storage, the moisture content of the bread crumb showed an almost linear decrease (Fig. 1). This decrease is probably due to the transfer of moisture from the crumb to the crust region of the loaf, as reported by Yasunaga *et al.* (6), since the total weight of the loaves did not change. The amount of free water in the crumb also decreased with increasing storage time. The decrease was quite rapid during the first 2 to 3 days of storage and then leveled off, so that there was essentially no change in the amount of free water from about 4 to 7 days. The amount of bound water showed very little change (a small decrease) during the initial 4 days of storage. Beyond 4 days' storage, there was a marked decrease in the amount of bound water.

These results indicate that during post-baking storage, bread crumb gradually loses moisture by transfer to the crust. Initially, it is primarily the free water of bread crumb which contributes to this loss of crumb moisture, but later, when the amount of free water reaches a low level, bound water contributes to the total moisture loss. The sharp decrease in the amount of bound water occurs at the time when bread staling (by organoleptic criteria) becomes particularly significant. Moreover, it appears that free water must reach a critical low value before bound water is lost from the crumb.

Effect of Added Fat

It is common knowledge that inclusion of fat in bread formula decreases the

TABLE I
Bread Formula and Procedure

Flour	100 g (14% mb)
Yeast	3 g
Salt	1 g
Sugar	2.5 g
Potassium bromate	1.5 mg
Ammonium phosphate	0.1 g
Malt	0.3 g
Water	4% less than farinograph absorption
Mixing	3.5 min
Fermentation	165 min at 30°C
Remixing	2.5 min
Refermentation	25 min at 30°C
Proofing	55 min at 30°C
Baking	25 min at 229°C
Determination of bread volume	25 min after baking

rate of bread staling. Accordingly, it was of interest to examine the effect of fat on bound water in crumb during storage.

The loaves with added fat showed a slower drop in bound water over the range of storage time investigated when compared with bread without added fat (Fig. 2). That is, the loaves with added fat retained comparatively more bound water and for a longer time.

If the results of Fig. 2 are compared with those of Fig. 1, it will be noted that the rates of decrease in the amount of bound water in the control loaves are quite different. Loss of bound water in crumb of bread from Pembina flour (Fig. 1) was considerably slower than that obtained for the bread from Manitou flour (Fig. 2). The significance of this cultivar effect was not investigated further in the present study, although it may be quite important in relation to baking technology.

Effect of Storage Temperature

The effect of storage temperature on the decrease of bound water in crumb with storage time is quite marked (Fig. 3). All loaves showed a fairly rapid initial loss which was highly temperature-dependent. The initial rates for the three temperatures were 0.20, 0.25, and 0.50 mg/mg dry matter/day for bread stored at −20°, 4°, and 26°C, respectively. The results for the two lower temperatures show that the equilibrium level of bound water is also temperature-dependent.

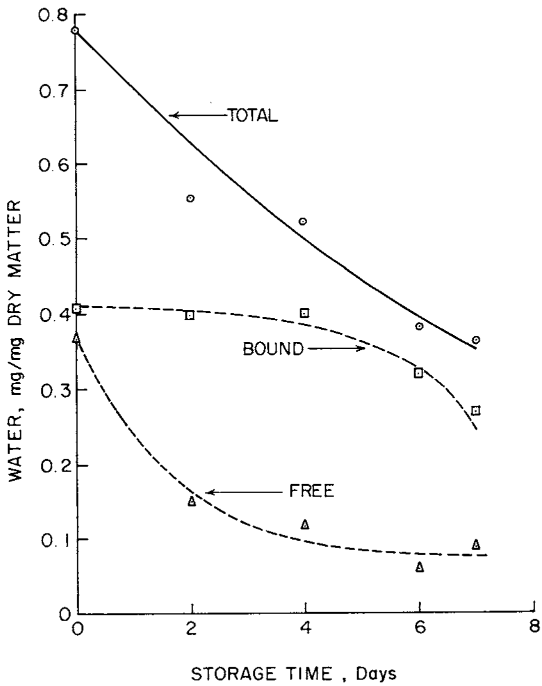

Fig. 1. Effect of storage time on total, bound, and free water contents of wheat bread crumb.

At −20° C, the equilibrium value was about 0.40 mg/mg dry matter, and at 4° C the value was 0.28 mg/mg dry matter. If the amount of bound water is related to freshness of bread (this hypothesis remains to be verified), these results indicate that bread stored for 25 days at −20° C is as fresh as bread kept at room temperature for about 1.5 days.

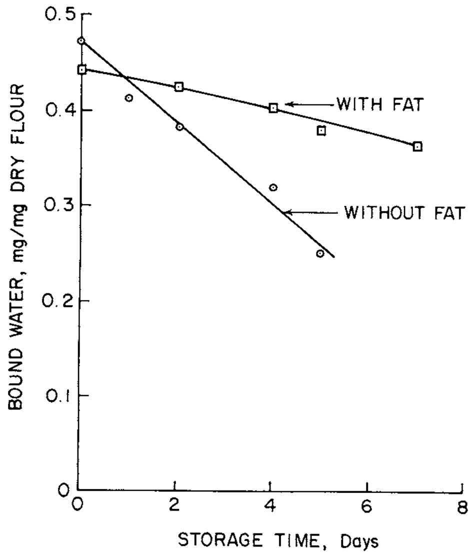

Fig. 2. Effect of added fat and storage time on bound-water content of bread crumb.

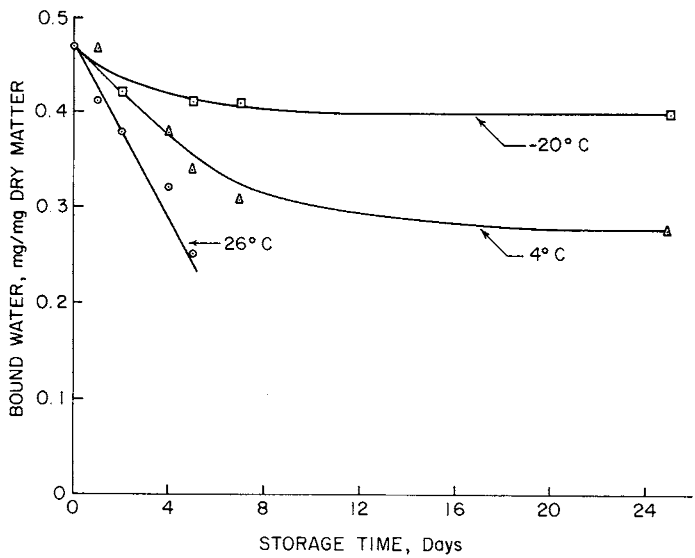

Fig. 3. Effect of storage temperature and time on bound-water content of bread crumb.

The effect of added fat was also examined in loaves stored at 4° and −20° C, in addition to the room temperature experiment discussed above. The results (not shown) showed that fat did not have any additional effect on the change in the amount of bound water compared with control loaves stored at these low temperatures.

Effect of Baking Absorption

It is common knowledge that the initial moisture content of the bread to some extent controls the rate of post-baking firming or staling (4). Loaves with higher initial moisture contents will remain fresher (softer) longer compared with loaves with a lower initial moisture.

All loaves for the three moisture levels used in this study showed a gradual decrease (essentially linear) in the amount of bound water in crumb with increasing storage time (Fig. 4). The curve for the super optimal absorption was consistently above the curve for optimal absorption. It is of practical interest to note that the amount of bound water in the super-optimal-absorption crumb after 2 days' storage was equal to that of freshly baked crumb at optimal absorption. Again, if the amount of bound water can be taken as an index of freshness, then these two loaves can be considered to be of equal freshness. Accordingly, it might be concluded that 4% additional water in the dough (if it can be handled by the bakery equipment) can increase the shelf-life of bread by about 2 days. Comparison of the three curves in Fig. 4 shows that the decrease in bound water with storage time was slightly slower in the bread baked at the higher moisture content than in bread baked at the two lower moistures.

In summary, results from the experiment on the effect of absorption indicate

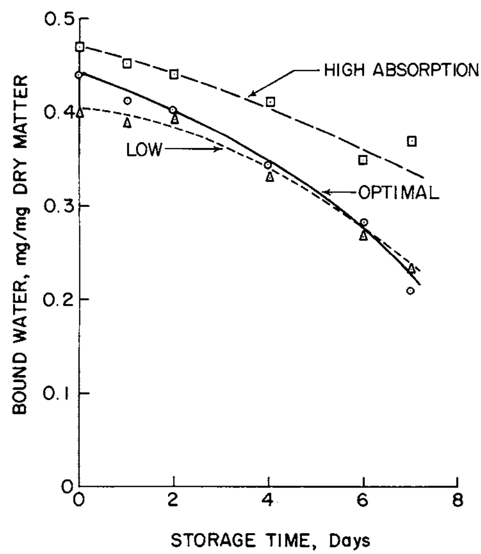

Fig. 4. Effect of baking absorption and storage time on bound-water content of bread crumb.

that it would be advantageous to use the maximum possible moisture content from the point of view of slowing down the rate of bread staling.

Effect of Protein Content

Loaves for this experiment were baked from three different flours milled from the variety Manitou, which has protein contents of 9.9, 12.4, and 14.1%. A constant baking absorption of 57.3% was used.

Although there was some fluctuation in the points for the three protein levels for each storage time, there was no definite trend with protein content (Fig. 5). All of the points fit a single curve. The amount of bound water in the crumb of bread from the three flours of different protein content decreased continually with storage time over the period investigated.

That the water binding of crumb from the three flours of different protein content was essentially the same could be due to the fact that all the loaves were baked at the same baking absorption (57.3%). This is the optimal absorption for the flour of medium protein (12.4%) content. Generally, baking absorption of similar flours increases with protein content. Accordingly, the well-known technological fact that bread from flours of higher protein content does not stale as rapidly as bread from flours of lower protein is probably due to its higher baking absorption. It was shown earlier that the crumb of bread baked at higher absorption had a higher bound-water content initially than crumb of bread baked at lower absorption. Also, the decrease in bound water during storage after baking was slower in bread baked at higher absorption.

On the basis of results described in this section, it is concluded that the known desirable effect of protein content on the rate of staling is probably indirect through its effect on baking absorption.

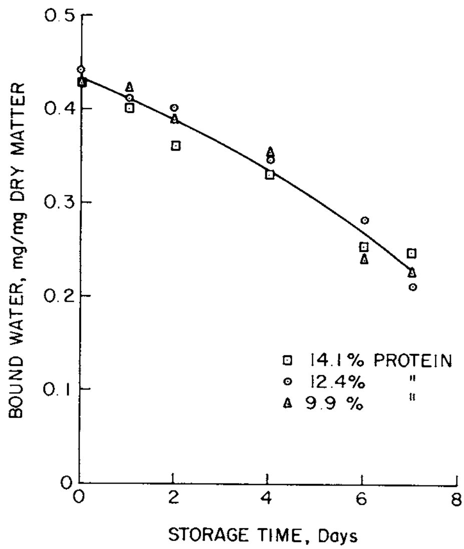

Fig. 5. Effect of flour protein content and storage time on bound-water content of bread crumb.

Effect of Starch Damage

Bread crumb from three flours with different levels of damaged starch used in this experiment had the same amount of bound water immediately after baking and followed the same rate of decrease with post-baking storage (results not shown). It appears that starch damage in the flour has no direct effect on the amount of bound water in the crumb of baked bread or on the rate of decrease of bound water with storage time. Starch damage could have an indirect effect on bound water (and presumably on staling) through its effect on baking absorption, which increases with increasing level of damage.

GENERAL DISCUSSION

Melting mode DTA can be used to measure the amount of and follow the changes in bound water of bread crumb during post-baking storage. Bound-water content of fresh crumb increased with increasing baking absorption and decreased with storage time. This decrease is significantly affected by storage temperature, added fat, and baking absorption. Results of this study suggest that there is a definite relation between bound-water content and staling of bread. It is postulated that crumb staling and decrease in the amount of bound water are related to the same physical changes in crumb constituents. According to this hypothesis, it should be possible to use bound-water content of bread as an index of bread staling.

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