Water Loss During Reheating of Fresh and Stored Cakes Made with Saturated and Unsaturated Monoglycerides[1]

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ABSTRACT

Water-loss rates and total water loss before and after storage were determined by reheating model cake systems made without emulsifiers and with saturated and unsaturated emulsifiers. Total water loss was not affected by type of emulsifier. Dynamic measurements of water-loss rates during reheating showed that the drying curves for cakes made with saturated emulsifiers changed with storage more than did cakes made without emulsifiers or cakes made with the unsaturated emulsifiers.

Although monoglycerides are often added to bakery products because of their antistaling properties, the role of emulsifiers in cake staling has not been properly examined (Herz 1965, Knightly 1968). In bread, the best antifirming effect was obtained from monoglyceride preparations that gave the highest amylose-complexing index (Krog and Nybo-Jensen 1970). The mechanisms in cake staling may be different from those in bread staling, so that functionality in bread systems may not apply to cake systems. Cakes, unlike bread, cannot be refreshed by reheating, and their shelf life can be extended by holding at refrigeration temperatures (Hodge 1977).

Starch recrystallization has been suggested as playing a major role in staling (Willhoft 1971a, 1971b, 1973; Hodge 1977), but the role in bread and cake may be quite different. Fearn and Russell (1982) and Axford and Colwell (1967) observed endotherms by differential scanning calorimetry (DSC) in stored bread crumb, which they interpreted as evidence of starch recrystallization. Cloke et al (1983), however, did not find comparable endotherms in stored cake crumb.

Another continuing question, as theories of staling have been developed, is the importance of total water loss versus that of moisture redistribution. Water loss and redistribution are usually considered both in the context of the effect on the sensory quality of the product (ie, qualities such as dryness and softness) and in relation to underlying physicochemical changes such as starch (and possibly lipid) recrystallization with concomitant moisture redistribution.

Recent studies of the rate of water loss during baking suggest that structural factors are important in determining how water is lost from the batter during baking. The role of additives such as emulsifiers appears to be primarily exerted through effects on structural development (Cloke et al 1984). Studies of heat and mass transfer can be useful in understanding these relationships during baking of cakes made with differing emulsive systems. Furthermore, reheating is a common way of refreshing baked products. Accordingly, this article reports the results of the study of heat and mass transfer during the reheating of freshly baked and stored cakes.

The heat and mass transfer in the cake crumb during reheating reflect conditions in the system quite different from those during baking. Cake crumb is a developed porous structure, whereas, during baking, the original batter emulsion-foam is being transformed into a porous structure. As a result of evaporative losses during baking, water content is reduced. Water sorption also occurs but is minor compared to evaporative losses and the water remaining in the system. Phase transitions occur during baking, and water is incorporated into the porous structure concomitant with these phase transitions. These phase transitions may be reversed during storage or by reheating, or, if incomplete, caused to progress further during reheating, resulting in further moisture redistribution. Water loss during reheating, therefore, can be viewed both as an indicator of water released into the developed structure and of its subsequent loss from the developed porous structure. The determinants of rates of water loss related to the original physicochemical transition and to the developed structure would be expected to be affected only minimally by storage. If, however, additional physicochemical changes that affect the release of water occur during storage, then differences between the fresh and stored would be present.

The purpose of our research was to evaluate water-loss rates during the reheating of freshly baked and stored lean research formula cakes made without added emulsifier and with 4% of the shortening replaced with either saturated or unsaturated monoglycerides. Total water loss and water activity were also determined. Parallel studies of the baking process including monoglyceride substitutions from 0.5 to 10% were described by Cloke et al (1984). For comparison of fresh and stored cakes, the 4% level was selected because it resulted in optimum crumb structure. Results for the complete series were previously reported by Cloke (1981).

MATERIALS AND METHODS

Test Formula and Cake Preparation

Details of the formulation and method of preparation were given by Cloke et al (1984). A saturated monoglyceride preparation

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containing 85–90% glycerol monostearate and 10–15% glycerol monopalmitate (Dimodan PV, Grinsted Products) or an unsaturated monoglyceride preparation containing 70% glycerol monooleate (Dimodan O, Grinsted Products) replaced 4.0% of the shortening (corn oil). All cakes were baked in a specially constructed environmental oven for 25 min at 191°C with an air-flow rate of 10.1 m^3/hr.

After baking, cakes were cooled at room temperature. Cakes were weighed immediately after baking and at intervals of 15, 20, 25, and 30 min after removal from the oven.

Storage and Reheating Experiments

Cakes were cooled for 1.25 hr in the cake pan before being cut into two pieces of approximately equal weight. Half was put into a clean cake pan, placed in a 2-qt plastic storage container with a tight snap-on lid, and stored at 4.1 ± 0.3°C for four days. The cake halves were then allowed to return to room temperature before they were reweighed and reheated. Fresh and stored halves were reheated in the environmental oven at 191°C with an air-flow rate of 10.1 m^3/hr for 1 hr. The rate of water loss was calculated from wet- and dry-bulb thermometry of the airstream entering and leaving the oven (Cloke et al 1984). A thermocouple was positioned in the crumb 5.1 cm from the sides of the pan. Three replications of treatment were baked.

Water Activity of the Fresh and Stored Cakes

Duplicate measurements of homogenized samples of fresh and stored cakes were made using the vapor-pressure manometer technique (Labuza et al 1976, Lewicki et al 1978). Cakes containing no emulsifier and 5 and 10% levels of saturated and unsaturated monoglycerides were examined. Fresh and stored cakes were homogenized in a Waring Blendor for 10 sec, stirred, and then homogenized twice more for 10 sec. Each homogenate was packed into two polyethylene Whirl-pak bags.

RESULTS AND DISCUSSION

Weight losses during the original baking were similar for cakes made with unemulsified shortening and for emulsified cakes and averaged 17.5 g or 8% of the original batter weight of 220 g. During the 30-min cooling period, weight losses averaged 3.2 g.

Center height of the cakes made with unemulsified shortening (1.9 cm) was somewhat less than that for cakes made with saturated monoglycerides (2.1 cm) or the unsaturated monoglycerides (2.6 cm). These differences in dimensions did not appear to be an important factor in the total weight loss.

Water activities of cake crumb ranged from 0.90 to 0.92, with no pattern associated with a particular emulsive system or with storage. Cake texture, however, was noticeably altered. After homogenization (in preparation for water-activity measurements) stored cakes had a doughlike texture, whereas fresh cake samples were in particulate crumbs. Cake crusts also became very sticky during storage. These observations suggest that a change in water distribution occurred, although the overall water activity did not change during storage. Bacharach and Briggs (1947) found small but significant increases in water-binding of stale bread (stored at 4°C for six days) when compared to fresh crumb and determined from relative vapor pressure-moisture content data.

Weight losses during reheating were similar for fresh and stored cakes in both the unemulsified cakes and in the cakes containing emulsifier. Weight losses in the emulsified cakes (27.3 g) were slightly smaller than those of the unemulsified cakes (28.3 g), but this difference was not statistically significant.

These results indicate that the nature of the emulsive system had a relatively small influence on water activity and overall weight loss during cooling, storage, or reheating and on the water activity. Previous studies of water-loss rates during cake baking have shown that water-loss rates versus time may be quite different, even though the total water losses are similar (Cloke et al 1984).

Water-loss rates versus time are plotted for the fresh and stored samples (Figs. 1 and 2, respectively) of the unemulsified cakes, and cakes containing saturated and unsaturated emulsifiers. The reheating curves were extended to a higher internal temperature (150°C) than was needed to complete the initial baking period (115°C) before storage. As a result, the reheating curves show an

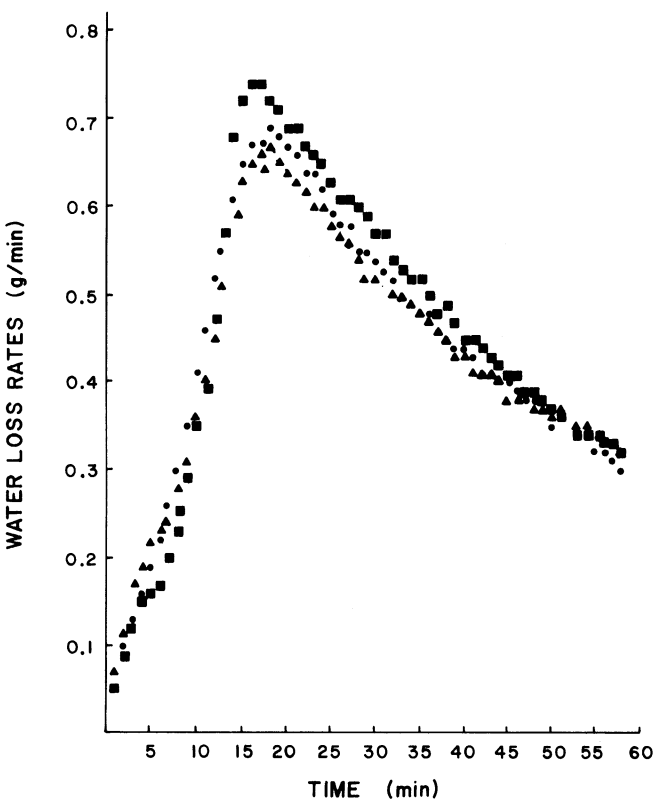

Fig. 1. Water-loss rates during reheating of fresh cakes made with no emulsifier (■) and with 4% levels of saturated (▲) or unsaturated (•) monoglycerides.

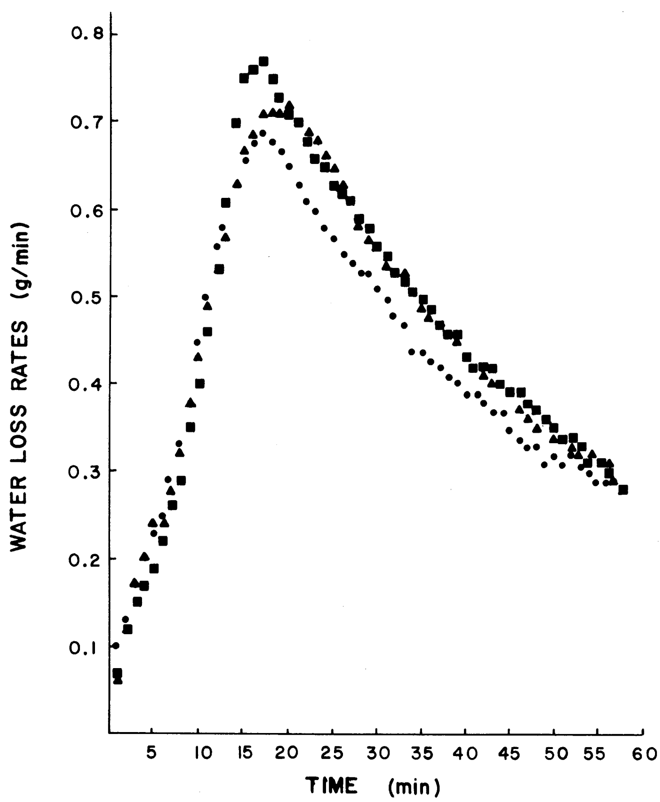

Fig. 2. Water-loss rates during reheating of stored cakes made with no emulsifier (■) and with 4% of saturated (▲) or unsaturated (•) monoglycerides.

extended drying or falling rate period in addition to the heating-up period that was characteristic of both the original baking and the initial phases of the reheating curves.

The general features of the curves for the fresh cakes were similar in all cakes (Fig. 1). Small differences in water loss were observed during the early stages of heating (5–7 min). During the major part of the heating-up period (up to 12 min) the water-loss rates for the three emulsifier systems were similar. As the samples approached and then reached the local maximum or constant rate period (15–18 min), the water-loss rate for the unemulsified system was greater than that for the two emulsified systems. During the falling rate period, the rates of the unemulsified cakes continued to be higher than in the emulsified samples. At the end of the falling rate period (from 50 min to the end of reheating), the rates again were very similar in all three systems. The rates at the local maxima and during the falling rate period were similar in the cakes containing saturated and unsaturated emulsifiers.

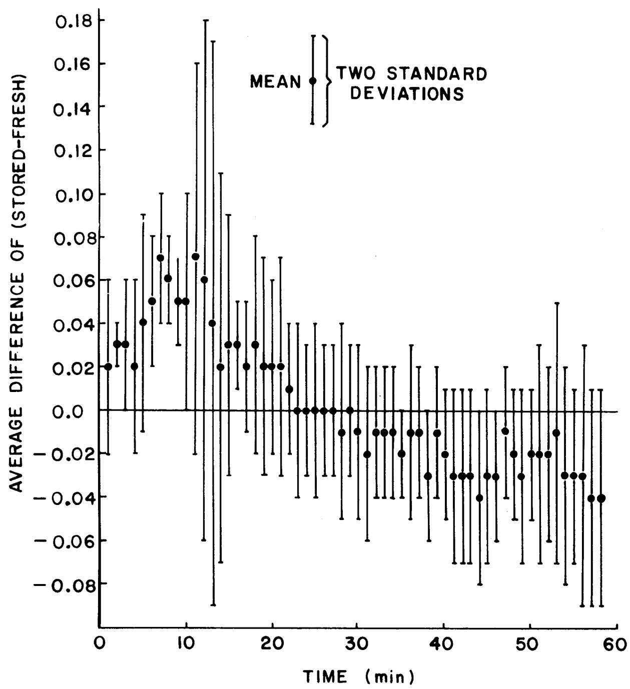

Fig. 3. Analysis of stored minus fresh differences in the water-loss rates for cakes made with no emulsifier.

The overall shapes of the water-loss rates of the stored cakes (Fig. 2) were similar for the three types of emulsifying systems, but the relative positions of the cakes containing the various emulsifying systems were different from those of the fresh samples. Water-loss rates during the heating-up period are similar, but rate differences begin to appear as the local maxima are approached (at about 12 min). Water-loss rates of cakes containing unemulsified shortening were again higher than in the rest of the cakes emulsified with saturated or unsaturated monoglycerides. However, the rates in the saturated monoglyceride-containing cakes were intermediate between those of cakes containing no emulsifier or unsaturated emulsifier. During the falling rate period, water-loss rates of cakes that contained unemulsified shortening and those that contained saturated emulsifier were essentially the same, and both were greater than those of cakes containing unsaturated emulsifier until the last few minutes of reheating. This represents an upward shift in the relative position of cakes made with saturated emulsifier.

Changes during storage that account for these shifts in water-loss rates are shown in Figs. 3, 4, and 5. In these figures, the differences and the ranges encompassing two standard deviations (± one standard deviation) between fresh and stored samples at each time interval are plotted for each type of cake. If storage had no effect, differences would cluster close to zero.

Stored cakes containing unemulsified shortening (Fig. 3) released water at a faster rate than did the fresh cakes during the early phase of reheating (about 6–10 min) and close to the maximum rate loss (20 min). During the falling rate period, the rates of the fresh and stored cakes were similar. Differences between the fresh and stored cakes in the early phases (6–10 min) and in the first part of the falling rate period (21–25 min) were more pronounced in cakes containing saturated emulsifiers (Fig. 4) than in cakes containing unemulsified shortening. Near the end of the falling rate period (47–50 min), the fresh cake had a higher rate of water loss than did the stored cakes. Stored cakes made with unsaturated emulsifier (Fig. 5) lost slightly more water than did the fresh cakes in the initial heating stages and slightly less during the final heating stages.

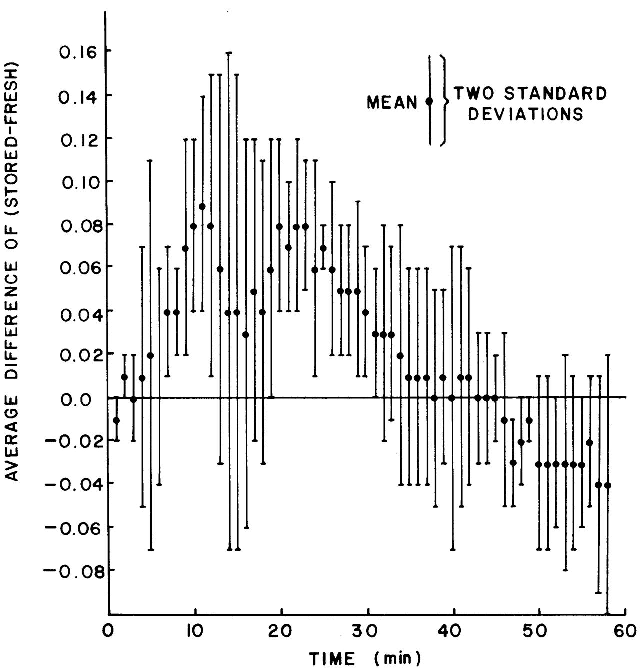

Fig. 4. Analysis of stored minus fresh difference in water-loss rates for cakes made with 4% level of saturated monoglycerides.

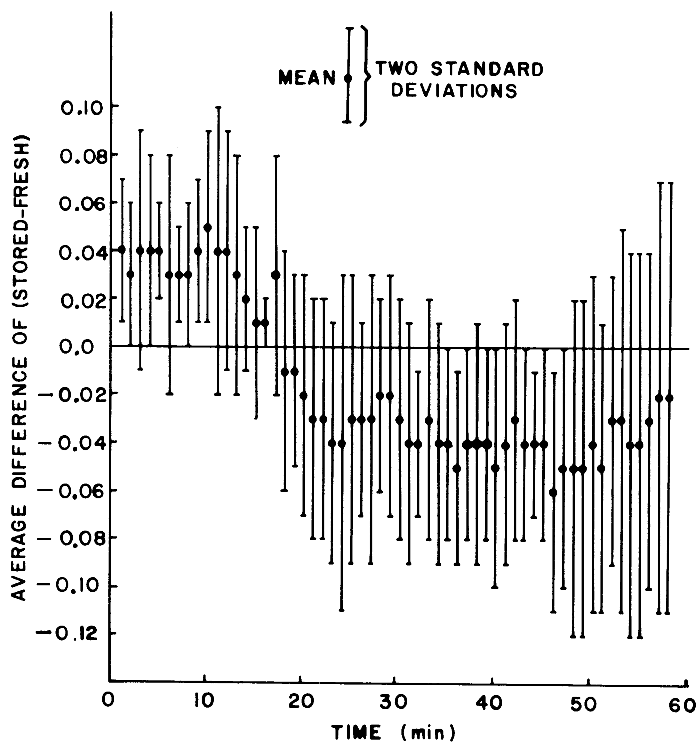

Fig. 5. Analysis of stored minus fresh differences in water-loss rates for cakes made with 4% level of unsaturated monoglycerides.

Generally, during heating of materials with a porous structure that contains water, the initial increase in water-loss rate is attributed to the effects of increasing temperature as the material heats up to the boiling point of water. The local maximum or constant rate period is maintained as long as there is sufficient water drawn to the cake surface to result in a constant rate of water loss. When this condition no longer exists, the drying curve enters the falling rate period. Two mechanisms are operative in the falling rate period. The first occurs when enough water remains to cause continuous capillary water flow through the porous medium. The second water loss occurs from discontinuous pools that form as the water content decreases. The transition between the two mechanisms is indicated by a change in slope of the falling rate curve.

Phase transitions in components such as starch and lipids may also occur as the porous medium is heated. Insofar as these alter the availability of water, the effects of these phase transitions will be superimposed on the mechanisms of water transport in the porous medium.

Differences in water-loss rates of fresh and stored samples indicate changes in water availability that result from changes in the components during storage. Elements of crumb structure such as pore size and distribution would not be expected to be affected by storage, but if pore shrinkage and matrix redistribution occurred, these factors could then become important.

All of the treatments showed some changes in rate of water release during the early stages of reheating that were attributable to storage. Water released during this time could be water that was loosely held within the crumb matrix. This may have contributed to the differences noted in homogenization of samples in preparation for water-activity determinations.

During the intermediate stage of reheating, which encompasses the time when samples approach and enter the first falling rate period, shifts in rate of water loss after storage were most pronounced in the saturated treatment. During this part of the falling rate period, cakes containing saturated emulsifiers released water at the same rates as did cakes made with the unemulsified shortening, and the cakes made with unsaturated shortening released the water more slowly.

This observation suggests that cakes made with saturated monoglyceride emulsifiers are more affected by storage than are cakes made with unsaturated monoglycerides. This consequence may be related to the behavior of the emulsion system. Differential scanning calorimetry studies (Cloke et al 1983) of model systems containing saturated monoglycerides showed that an endotherm was present in reheated samples that had similar initial thermal transition temperatures (58° C initially versus 52° C reheated), but a lower enthalpy (37 cal/g versus 15 cal/g) than was found during the initial heating of the monoglyceride system. This was interpreted as indicating partial recrystallization of the monoglycerides. Freeze-fracture studies of these samples (Cloke et al 1982) showed that the distribution of oil and monoglycerides was also affected by the type of emulsifier present. Mesophases formed by various monoglycerides have been shown to bind water differentially, and this could contribute to water availability.

Differential scanning calorimetry studies of the starch system did not show evidence of recrystallization during storage as no endotherm was observed during reheating of cake crumb or model systems containing starch (Cloke et al 1983). Such endotherms have been observed in bread (Fearn and Russell 1982, Axford and Colwell 1967), suggesting again that the staling mechanisms in cakes and bread are different.

When a product is refreshed by heating, the reheat curves suggest that any changes in sensory properties would reflect a loss of water from the crumb and the accompanying physicochemical changes that contribute to it. Storage affected the release of water from cakes made with saturated emulsifiers more than unemulsified cakes or cakes made with unsaturated emulsifiers. Emulsifiers, therefore, affect movement of water during baking and refreshing through the developed porous structure of cake crumb (whose structure and distribution of components within and on the surface of the capillary network is initially influenced by the emulsifiers). Emulsifiers also affect the release of water during physicochemical transitions such as those of starch and lipids.

CONCLUSIONS

Weight losses during baking, cooling, storing, and reheating of cakes made without emulsifier and with 4% saturated or unsaturated monoglycerides were very similar. Water activity of fresh and stored cakes was also similar. Dynamic measurements of water-loss rates during reheating resulted in drying curves that were characteristic of drying curves for porous media. Drying curves for cakes containing saturated monoglycerides showed greater changes after storage than did cakes made of the unemulsified shortening or with shortening containing unsaturated monoglycerides. This change indicates that the saturated emulsifier had greater influence in the retention of water within the cake crumb after the initial baking period.

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