Effect of Sodium Chloride and Sodium Dodecyl Sulfate on Mixograph Properties[1]

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ABSTRACT

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The effects of sodium chloride and sodium dodecyl sulfate (SDS) on mixograms were studied. Sodium chloride (2–5%, flour basis) increased the width and height of the mixogram curve and increased mixing time. Mixing time was increased from 4 to 7 min when Kansas State University flour was mixed with 5% NaCl. Adding low levels of SDS (0.5–1.0%, flour basis) markedly increased mixing time; higher levels (2 and 3%) progressively shortened mixing time. When dry NaCl or SDS was added to doughs overmixed in the presence of potassium iodate, ferulic acid, or *N*-ethylmaleimide, the mixogram curves were rapidly widened and increased in height. The effect of overmixing is essentially reversed by NaCl or SDS. The mixogram curve heights after SDS was added were essentially the same as those of optimally mixed dough, regardless of the amount of breakdown during overmixing. In contrast, NaCl gave higher mixogram curves. A model of dough development and breakdown is presented.

The conversion of flour and water into a dough by mixing is a complicated process (Hoseney and Finney 1974). When common dough ingredients such as salt are added, the process becomes even more complicated. Hlynka (1962) reported that salt increased dough development time. A strong interaction also occurs between pH and salt in doughs (Galal et al 1978, Tanaka et al 1967). In the absence of salt, dough's resistance to extension increases as pH decreases; its resistance decreases in the presence of salt. Galal et al (1978) found that salt increased both mixing time and dough stability.

When dough is mixed beyond peak development, another set of complicated changes occurs: the dough's resistance to extension decreases. The effect is much greater if dough is mixed with activated double-bond compounds (fumaric acid, ferulic acid, or *N*-ethylmaleimide (NEMI), or fast-acting oxidants such as potassium iodate. The changes with overmixing have been the subject of a series of studies (Danno and Hoseney 1982a, 1982b; Schroeder and Hoseney 1978; Sidhu et al 1980a, 1980b; Weak et al 1977). The general conclusion is that disulfide bonds are broken during mixing to create thiyl radicals, which react with the activated double-bond compounds. Grafting those compounds to the protein apparently causes the decrease in dough's resistance to extension. The work reported here was designed to extend our knowledge of overmixing by studying the effects of salt and sodium dodecyl sulfate (SDS) on doughs.

MATERIALS AND METHODS

The flour used in this study was milled on the Kansas State University (KSU) experimental mill from a composite of hard winter wheat (10% protein, 0.37% ash). SDS (99% pure) was obtained from Polysciences Inc., Warrington, PA. Sodium chloride was reagent grade. A 10-g mixograph was used to mix doughs (Finney and Shogren 1972).

RESULTS

Sodium Chloride

The effect of NaCl on dough-mixing is shown in Fig. 1. Salt (0–10%, flour basis) was added to the water before starting the mixograph. Increasing amounts of salt up to 5% increased the width and height of the mixogram curve. At 10% salt, the flour did not mix into an elastic dough. Essentially the same results were obtained with a second flour of higher protein content.

The mixing time of the flour when mixed with 5% salt increased from 4 to 7 min. Adding 5% dry salt to the flour gave essentially the same mixograms as those obtained when 5% salt was added as brine (data not shown). Sanchez et al (1973) reported that adding 2% dry salt to flour lengthened mixing time, but adding 2% salt as brine did not.

When we added 5% dry salt to a dough mixed for 10 min (overmixed, curve not shown) or in the presence of 70 ppm potassium iodate (Fig. 2), it rapidly broadened the thin mixogram tail and increased curve height. Similar results were obtained with doughs that had been overmixed in the presence of either ferulic acid or NEMI (Fig. 2). In all of these cases, curve height and width were greater after 5% salt was added than in the original peak.

SDS

Adding small amounts of SDS to flour-water mixograms increased mixing time (Fig. 3). Moderate concentrations of SDS (0.5 and 1%) gave similar curves and wide mixogram curves at the peak. However, even higher levels of SDS (2 and 3%) gave progressively shorter mixing times (Fig. 3). Essentially the same results were obtained with a second flour of higher protein content.

When 1% dry SDS was added to overmixed dough, the mixogram tail rapidly broadened, and the height of the mixogram curve returned to that of an optimally mixed dough (Fig. 4). When 1% dry SDS was added to dough overmixed in the presence of ferulic acid or NEMI, the thin and low mixogram was rapidly broadened, and the curve height increased to that of optimally mixed dough (Fig. 4). Similar results were obtained with dough overmixed in the presence of 30 ppm potassium iodate (curve not shown). In all these cases, the mixogram curve heights after 1% SDS was added were the same, regardless of the degree of breakdown. Those results differ markedly from results with sodium chloride, because the curve heights varied more with salt.

DISCUSSION

When NaCl was added to flour before dough was mixed, mixing time to reach the peak was progressively lengthened, and wider mixograms were obtained; up to 1% SDS gave essentially the same results. Higher levels of SDS progressively decreased mixing time. Thus, the effect of SDS on mixing time appears as a bell-shaped curve.

An examination of the mixograms shows that the delay in mixing results from flour hydrating at a slow rate (low narrow curve at the start), which can be explained as follows. In a flour-water system the flour protein has a net positive charge, which, because of its repulsive forces, makes the protein hydrate faster. Adding low levels of SDS or high levels of NaCl either neutralizes or shields the charge, making the protein hydrate slowly. The mechanism is as Bernardin (1978) suggested; higher levels of SDS will bind hydrophobically with the protein, giving it a net negative charge. This will again make the protein more hydrophilic and thus it will hydrate more rapidly and give the shorter mixing times, as seen in Fig. 3.

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When NaCl or SDS was added to overmixed doughs, the mixogram curve rapidly broadened and increased in height. Similar results were obtained when dry SDS or NaCl was added to doughs overmixed with NEMI, ferulic acid, or potassium iodate; the thin mixogram rapidly broadened and curve heights increased. As a result of overmixing, the above reagents gave markedly decreased curve heights and widths (Schroeder and Hoseney 1978, Sidhu et al 1980b, Weak et al 1977). Thus, SDS or NaCl reverses the effect of overmixing and of activated double-bond compounds on overmixing.

That SDS and NaCl reverses the effect of overmixing is surprising. We had always considered overmixing irreversible. To understand how those reagents reverse the effect, one must first understand what happens during overmixing. Unfortunately, our understanding of overmixing is incomplete.

During mixing, flour particles are hydrated, and the gluten protein is developed into a partially elastic but still flowable mass, which we know as dough. Continued mixing probably stresses certain disulfide bonds to the extent that they break and form two thiyl radicals. Breaking the bond, although apparently an important step in overmixing, does not in itself produce a weakened mixing curve (Danno and Hoseney 1982b).

An activated double-bond compound apparently is necessary for rapid breakdown. Evidence to support those conclusions includes the lower viscosity of extracted proteins from overmixed flour (Danno and Hoseney 1982b) and the fact that gluten plus starch (removal of the water-soluble fraction of flour that contains the indigenous activated double-bond compound) give excellent mixing stability (Schroeder and Hoseney 1978), even though the viscosity of the protein extracted from the dough decreases with overmixing (Danno and Hoseney 1982b).

Additional evidence was provided by adding enzyme-active soy flour (lipoxygenase) to flour. Lipoxygenase gave excellent mixing stability but did not alter the decreased viscosity of the proteins extracted from overmixed doughs (Danno and Hoseney 1982b).

That the activated double-bond compound causes the rapid

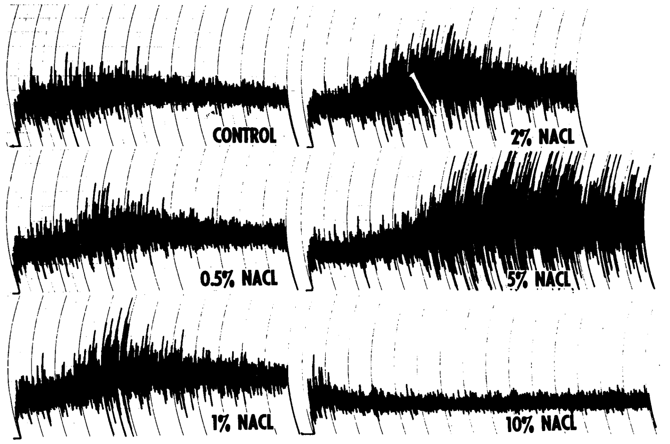

Fig. 1. Mixograms of doughs containing indicated amounts of sodium chloride.

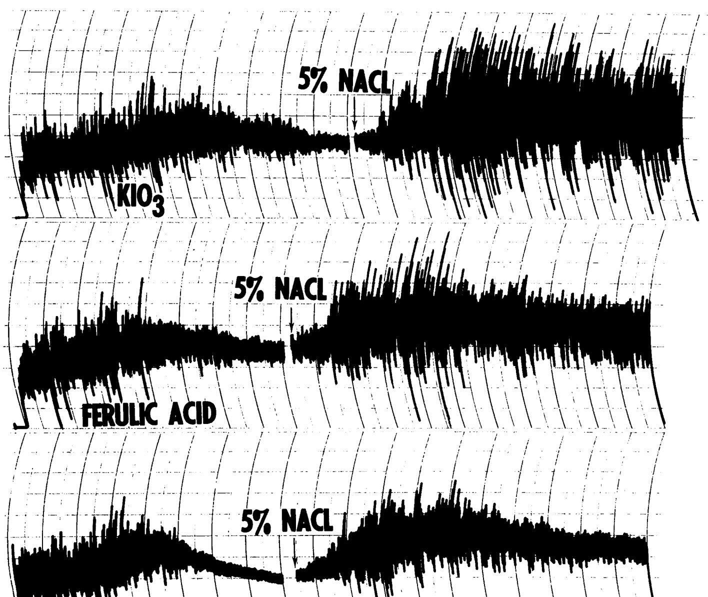

Fig. 2. Mixograms of doughs overmixed (10 min) in the presence of KIO_3 (70 ppm), ferulic acid (250 ppm), or *N*-ethylmaleimide (NEMI) (250 ppm) and the overmixing effect reversed with 5% NaCl.

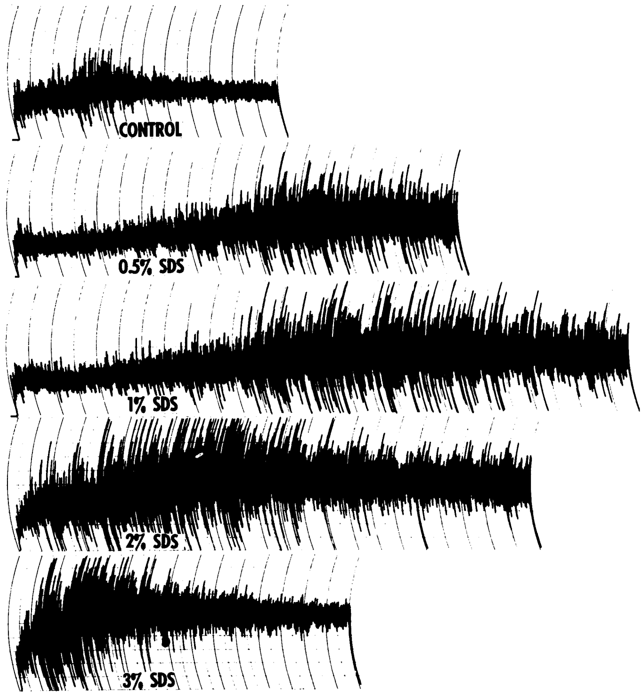

Fig. 3. Mixograms of doughs containing indicated amounts of sodium dodecyl sulfate (SDS).

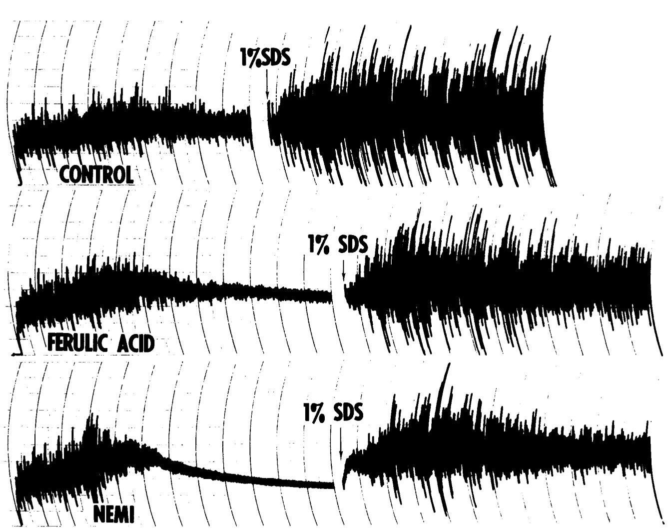

Fig. 4. Mixograms of overmixed (10 min) dough and dough overmixed in the presence of ferulic acid (250 ppm) or *N*-ethylmaleimide (250 ppm), and the overmixing effect reversed with 1% SDS.

breakdown independently of the thiyl radicals must also be considered. The strongest evidence that the thiyl radical is involved is that free radical scavengers such as butylated hydroxyanisole and butylated hydroxytoluene BHA and BHT give curves with good mixing stability even in the presence of activated double-bond compounds (Schroeder and Hoseney 1978). The above data and the work of Sidhu et al (1980b) showing that the activated double-bond compound adds to the thiyl radical indicates that the addition is the mechanism of rapid dough breakdown.

The changes that result from overmixing, and particularily overmixing in the presence of fast-acting oxidants or activated double-bond compounds, are truly remarkable. Within a few minutes in a mixograph, the dough changes from a strong, dry, elastic mass to a sticky, wet mass with essentially infinite extensibility and no elastic properties. Perhaps just as remarkable is our finding that SDS or NaCl will reverse overmixing effects and give a dry, elastic dough again.

To explain the data, we propose the following model, which is consistent with the data but highly speculative. The glutenin proteins have large molecular weight. Even in such dissociating solvents as SDS, values as high as 5 million are reported (Danno and Hoseney 1982a). If the average subunit of glutenin has a molecular weight of 100,000 (perhaps a somewhat high estimate), 50 subunits are found per molecule. Amino acid data have shown five sulfhydryl groups per 100,000 mol wt for glutenin; of course, most, if not all, are disulfides. If each subunit is linked to two others by only one intermolecular disulfide bond, then, on the average two intramolecular disulfide bonds exist per 100,000-mol-wt subunit. The glutenin molecule reacts with lipids (Olcott and Mecham 1947) mainly by hydrophobic bonds (Hoseney et al 1970). Thus, we speculate that the glutenin molecule occurs in optimally mixed dough in a macrospherical or helical structure with a hydrophobic surface and a hydrophilic interior. As a result of overmixing, few of the disulfide bonds are broken (perhaps one or fewer than one of the 125 disulfide bonds in a glutenin molecule of 5 million mol wt). No evidence suggests that an intermolecular or intramolecular bond on the subunits is stressed and broken. Adding an activated double-bond compound to the thiyl radical causes the glutenin molecule to invert and become hydrophilic on the exterior and hydrophobic in the interior. That gives the dough a large excess of water, hidden previously in the glutenin molecule. This excess results in the wet, sticky dough with no elasticity. Adding SDS or NaCl to the overmixed dough masks the positive charges, now on the exterior of the glutenin. Without the positive charges, the glutenin reverts to the original configuration of a hydrophobic exterior and a hydrophilic interior, which causes the dough to regain its dry, elastic properties.

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