ELECTRICAL CONDUCTIVITY OF FLOUR SUSPENSIONS AND EXTRACTS IN RELATION TO FLOUR ASH[1,2]

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ABSTRACT

Electrical conductivities of flour extracts were directly related to flour ash, and log-log plots of ash *vs.* specific resistance were essentially linear. Conductivities of flour suspensions were lower than of corresponding extracts due to electrolyte displacement, but suspensions were studied to determine effects of time and temperature on equilibration rates. Conductivities equilibrated rapidly in aqueous suspensions of low-ash flours, but conductivities of suspensions of high-ash flours continued to increase after 90 min. Heat treatment (15 min at 100°C) accelerated equilibration, but increased conductivities of low-ash flours and decreased conductivities of high-ash flours. Enzymes might be involved in the steady increase in conductivities of suspensions of high-ash flours during incubation at room temperature. Conductivity measurements, which are convenient and rapid, might be a useful index of flour quality.

In 1918, Bailey noted a positive correlation between ash levels and electrical conductivity of flour extracts and suggested conductivity as a criterion of flour grade (1). Further studies showed that a plot of conductivity against ash gave a parabola, and that prolonged incubation during extraction increased conductivity (2). Collatz and Bailey (3) attributed the increase to dissociated phosphates produced from the action of phytase on phytin.

Electrical conductivity was used to monitor salt concentrations in extracts and washings in recent investigations of the effects of salts on gluten systems (4). It was established empirically that, for a particular salt species, a plot of the log of specific resistance [or log (1 ÷ specific conductivity)] against log of salt

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[2]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of a product by the U.S. Department of Agriculture, and does not imply its approval to the exclusion of other products that may also be suitable.

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concentration was linear over a wide range, and such plots were determined for four salts (Fig. 1). The objectives of this study were to determine whether the relation between flour ash levels and conductivities of flour extracts is linear, and to determine the contribution of endogenous salts to conductivities of flour extracts and suspensions. Distributions of ash among flour extracts and fractions were reported in a separate paper (5).

MATERIALS AND METHODS

Flours

Flours and millstream flours were sampled from routine millings carried out in the Wooster Laboratory on either a MIAG Multomat mill or an Allis Chalmers laboratory test mill.

Ash

Ash was determined gravimetrically after incineration of flours at 550° C for 15 hr and expressed on a 14% moisture basis.

Conductivity Measurements

Conductivities were measured on a direct-reading meter with a range of 0–500 m mho (Radiometer Type CDM2e). Extracts were measured in a 1-ml pipet-type cell (Radiometer Type CDC114) and suspensions were measured in a 20-ml beaker-type cell (Lab-Line Model CE/01) agitated with a magnetic stirrer. Conductivity, measured at 25° C, was converted to specific resistance after correction for cell constant.

Extractions

Water (20 ml, double deionized, conductivity 0.5–1.0 μ mho/cm) was pipetted into 50-ml centrifuge tubes, and preweighed samples (1 g, ±0.01 g) of one set of millstream flours were added to each tube in turn as rapidly as possible. Tubes were capped, shaken vigorously and often for 1 hr, and centrifuged at 10,000 × g. Supernatants were collected and quickly brought to boiling, immediately cooled to 25° C, and conductivities were determined. For heat treatments, tubes of suspensions were placed in boiling water for the specified time, shaken frequently and vented, and cooled before centrifuging. Heated extracts were not boiled before conductivity was measured.

Conductivities of Suspensions

Flour and water were mixed in the specified ratio (1:4 or 1:20), and the suspension was transferred immediately to the beaker-cell. The magnetic stirrer was started, and conductivity was measured at the specified intervals. Before each reading, the suspension was stirred vigorously with a polyethylene paddle, and the temperature was adjusted to 25° C by suspending a test tube containing hot or cold water in the cell. For heated suspensions, mixtures were placed in boiling water for the specified time, and cooled rapidly before transfer to the cell.

Displacement effects were studied by addition of 20 ml 0.01 M sodium chloride to the beaker cell. Conductivity was determined, starch (1 g, 2 g, or 5 g) was stirred in, and conductivity was again measured before the starch settled.

Conductivity was measured at intervals as the suspension settled, and again after the starch had been resuspended by stirring.

RESULTS AND DISCUSSION

Figure 1 illustrates the relation between electrolyte concentration and conductivity that is the basis for this study. For sodium chloride, linearity

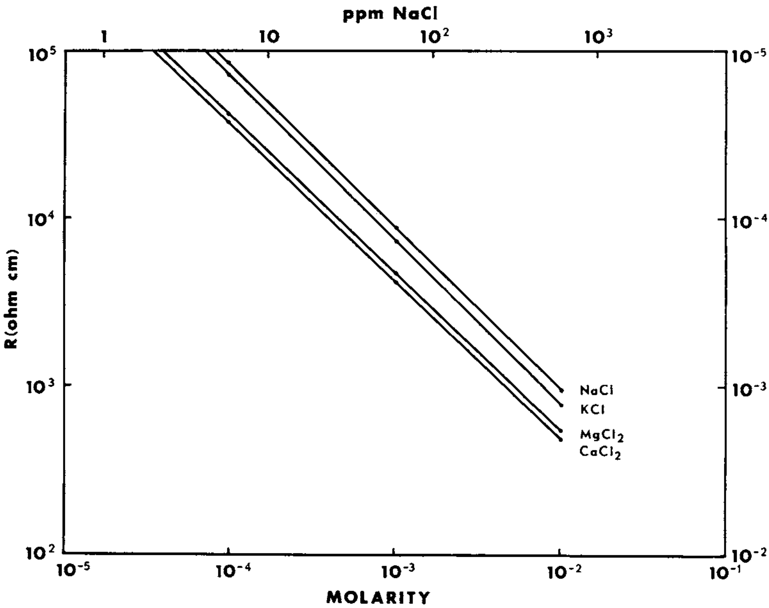

Fig. 1. Specific resistance *vs.* molarity (log-log) for the chlorides of sodium, potassium, magnesium, and calcium.

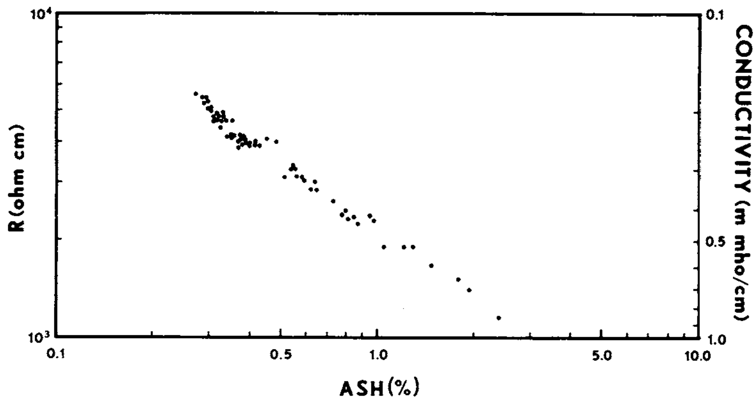

Fig. 2. Flour ash *vs.* specific resistance for extracts of seven sets of millstreams (ten streams per set). Extraction conditions: 1 g flour + 20 ml water + 1 hr at room temperature.

extends from 0.1M beyond 0.00001M. In a complex system, conductivity is a function of ionic species, solubility, degree of ionization, and various interactions. From the practical standpoint, it is more convenient to plot specific resistance than conductivity (the reciprocal of resistance). In the following discussion, the term conductivity will be applied in a general sense, although results may be expressed in resistance units.

Figure 2 presents data from aqueous extractions (1:20, flour:water) of flour streams from seven millings (different varieties and blends) on a MIAG Multomat mill. Extracts were equilibrated for 1 hr at room temperature before centrifuging. The plot is essentially linear, and in general agrees with conductivity measurements of known electrolytes.

Millstream flours from a soft wheat mix were suspended in water (1:4, flour:water) in the beaker cell at room temperature, and conductivities were measured at intervals for 90 min to determine effects of time (Fig. 3; two streams omitted for clarity). Conductivities remained in the same order as ash levels throughout the incubation period. The low-ash flours equilibrated rapidly and changed little after 15 min, but conductivities of the high-ash streams increased steadily throughout the 90 min, and streams with intermediate ash contents exhibited intermediate slopes. The range of conductivities among streams

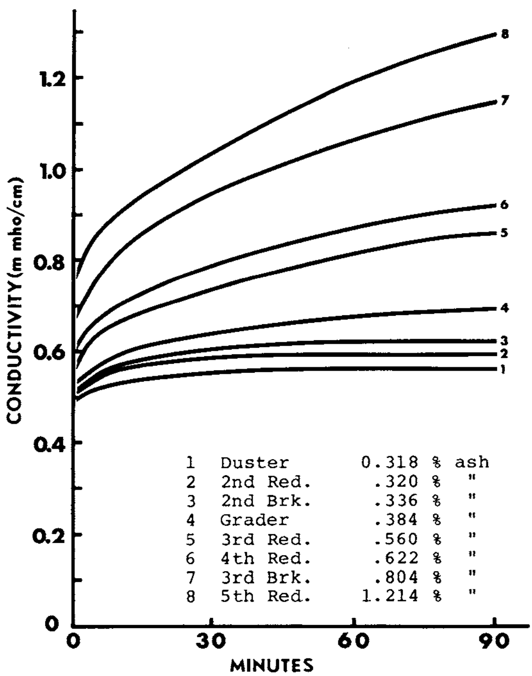

Fig. 3. Effect of incubation at 25°C on conductivities of slurries of mill streams from a soft red blend (Arthur + Logan). Conditions: 5 g flour + 20 ml water in beaker cell, with constant stirring.

increased greatly during incubation, and because of the relation of slope to ash, the effect of prolonged incubation was slight on low-ash streams, but pronounced on high-ash streams.

These measurements indicated that conductivities were much lower for suspensions than for corresponding supernatants after centrifugation. Electrical conductance through a given volume of solution decreases if the solution is displaced by solid particles; the decrease is proportional to the volume displaced, even when the particles are conductors (6). Figure 4 shows the effect of starch on the conductivity of 0.01M sodium chloride. When the starch was stirred into the salt solution, conductivity was immediately depressed in proportion to starch concentration. As the starch settled below the electrodes, conductivity was restored (and even exceeded the initial value, presumably because of electrolytes from the starch). When the starch was resuspended, conductivity was again depressed. Presumably, the displacement effects of flour solids on conductance of flour-water suspensions would be similar. Therefore, in comparisons of

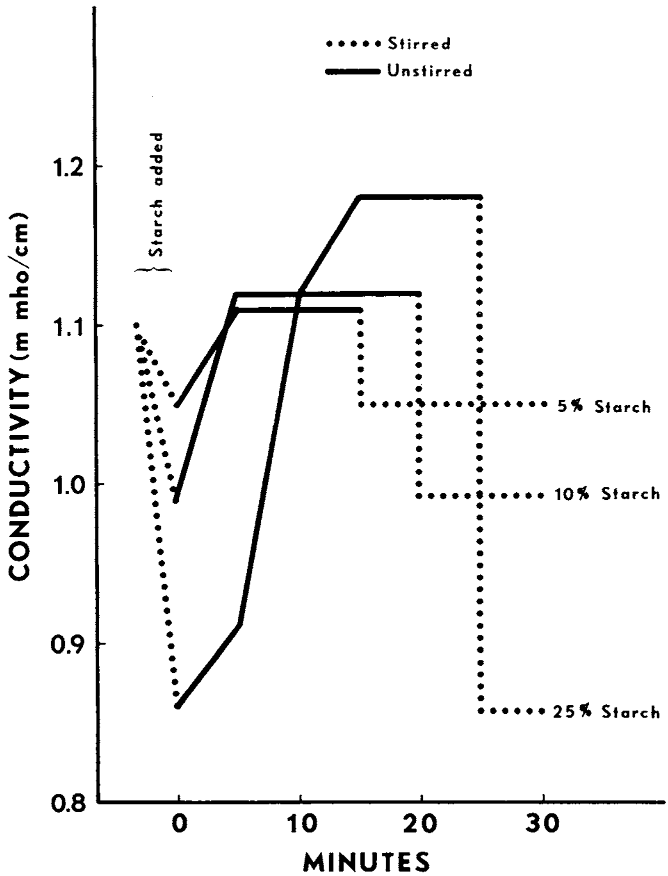

Fig. 4. The effects of added starch on specific conductivity of 0.01M sodium chloride.

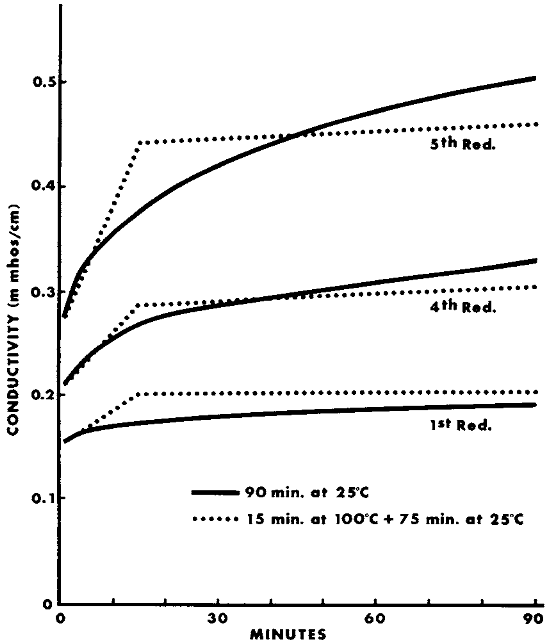

Fig. 5. Effect of heat treatment on conductivities of slurries of three different millstreams from a milling of Clarkan wheat. Conditions: 1 g flour + 20 ml water in beaker cell, with constant stirring.

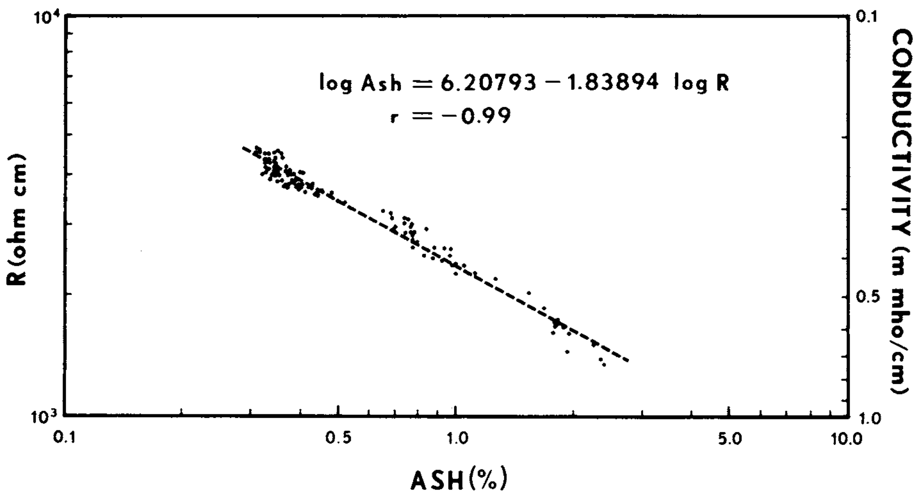

Fig. 6. Flour ash *vs.* specific resistance for extracts of twelve sets of millstreams (ten streams each). Extraction conditions: 1 g flour + 20 ml water + 15 min at 100°C.

conductivity of suspensions and extracts, allowance must be made for displacement effects.

Figure 5 shows examples of conductivity curves of suspensions (1:20, flour:water) incubated at room temperature, and of suspensions heated 15 min at 100°C prior to incubation to determine the effects of heating on equilibration rates. The flour streams illustrated are the first, fourth, and fifth reductions (0.322, 0.750, and 1.533% ash, respectively) from a milling of Clarkan wheat. These results, together with data from similar treatments of other flours can be summarized as follows: When suspensions of low-ash flours were heated and then incubated at room temperature, conductivities were higher than those of suspensions incubated without heating, but when high-ash flours were heated and incubated, conductivities were lower than those of unheated suspensions. Heating resulted in an immediate increase in conductivity, but subsequent incubation of heated suspensions resulted in little change. Heating thus accelerated equilibration, but reduced the spread among conductivities. The results suggest that heating increases the rate of solubilization of minerals, but inactivates enzymes which liberate electrolytes during long-term incubations.

Because heating resulted in rapid equilibration and minimized time effects, conductivities were determined on a relatively large number of samples heated 15 min at 100°C during extraction. The study included 12 sets of millstream flours (118 samples) from various soft white, soft red and hard red winter varieties milled on a MIAG Multomat mill, with ash ranging from 0.304 to 2.420% (14% moisture basis). Results are presented in Fig. 6. The pattern was similar to that from extracts obtained by equilibration for 1 hr at room temperature (Fig. 2), but a reduction in slope was evident. A regression line (based on a total of 118 measurements) corresponds to the linear expression.

$$\log \text{Ash } (\%) = 6.20793 - 1.83894 \log R$$

where R is specific resistance. The regression has a correlation coefficient (r) of −0.99.

These experiments have shown that conductivities of flour extracts obtained under standardized conditions are directly related to flour ash, and this relation is essentially linear on a log-log plot. The proportion of total minerals extracted under the usual conditions decreases with increasing mineral content (5), which indicates that the proportion of bound or insoluble mineral is higher in high- than low-ash tissues. Conductivity is a function of ionic species (7) (Fig. 1), and application of the linear relation assumes that the electrolyte population is qualitatively constant. However, qualitative differences exist among wheat samples and among tissues (*e.g.*, bran *vs.* endosperm) (8,9), and such differences could contribute to deviations. On the other hand, electrical conductivity represents a direct indication of electrolyte level in a particular system, as opposed to ash, which is a measure of total mineral content. Since electrolytes are directly implicated in flour behavior in aqueous systems, conductivity may serve as a useful index in determinations of baking quality. Measurement of conductivity is simple, rapid and amenable to automation.

Acknowledgments

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