Influence of Various Salts and Water Soluble Compounds on the Water and Fat Exudation and Gel Strength of Meat Batters

R.C. WHITING

ABSTRACT

Meat batters were prepared in which the sodium or chloride from salt was replaced by other ions. Then the functional properties of the batters were determined by measuring water and fat exudation, and gel strength. Generally cations from groups IA and IIA of the periodic table equalled or surpassed the batters made with sodium only, whereas other cations decreased water binding. Of the anions, bromide, ortho- and pyrophosphates, and citrate increased water retention. Zinc chloride increased fat exudation greatly. Magnesium chloride and sodium pyrophosphate increased the gel strength. Magnesium and calcium chlorides made good batters although they caused a drop of approximately 0.25 pH units. Sodium thiosulfate, sodium borohydride, starch, sucrose, glycerol, arginine and urea improved the water binding and gel strength, while nonionic detergents, monoglycerides and alcohols were very detrimental.

INTRODUCTION

FOR PRODUCTION of successful meat batters with good water and fat binding and optimum texture, the myosin or actomyosin proteins must be suspended-solubilized, denatured and then aggregated by heat to form a gel structure (Gaska and Regenstein, 1982; Acton and Dick, 1984; Ziegler and Acton, 1984). With insufficient suspension-solubilization, there is not enough protein available to form the gel. If extensive aggregation precedes or accompanies denaturation, a floc or precipitate will form. The slower the aggregation step relative to denaturation, the finer and more oriented the gel network will be. Excessive loss of water or fat resulting in a mushy or mealy texture may result from failure to form a gel or from formation of an excessive number of interprotein bonds that decrease the water binding ability and the capillary spaces that trap water. A successful gel is a balance between protein-water and protein-protein interactions. Protein gels were observed to form when conditions changed from promoting solubility to promoting either insolubility or aggregation (Hegg, 1982). Salt is added as the solubilizing agent for the proteins in meat batters; generally a 4.0% brine is necessary to insure a good batter (Acton et al., 1983). Therefore, reducing the contribution by meat products to the dietary sodium necessitates an increased knowledge of the factors important in creating a good meat batter.

Some effects resulting from changing the lipid phase components of the meat batter were noted (Whiting, 1987). Triglyceride composition had only a small influence; lecithin, cholesterol and methyl palmitate, a detrimental influence; and sodium laurate, a beneficial influence on the functional properties. In this paper, various salts and nonionic water soluble substances were added to meat batters to: (1) determine which salts were beneficial or detrimental, (2) examine other water soluble compounds that might affect the batter, (3) provide some insight into the chemical processes that formed and stabilized the batter, and (4) find possible alternatives to sodium chloride.

Author Whiting is with the USDA-ARS, Eastern Regional Research Center, 600 East Mermaid Lane, Philadelphia, PA 19118.

MATERIALS & METHODS

BEEF BOTTOM ROUND and pork adipose tissue were obtained from local abattoirs and stored at 1°C until used. All procedures for proximate analyses of the beef and pork, making the batter, measuring the batter's water binding, fat binding and gel strength and statistical analyses were as reported (Whiting, 1987). The standard batter formulation of 180g contained 95g lean beef, 49g pork adipose tissue, and 32g ice. The 0.45M NaCl was calculated on the aqueous phase and corresponded to 2.0% salt based on the entire batter or 3.1% brine. This slightly low salt level was chosen to form a marginal batter which could show either positive or negative changes. All ingredients were added to the chopping bowl of a food processor (Cuisinart CFP-9) and chopped with brief interruptions to scrape the sides of the bowl and to measure the temperature until 16.0 ± 0.5°C was reached. The pH of the uncooked batters was measured by insertion of a combination electrode and automatic temperature compensator directly into the batter.

Three 30 ± 0.1g aliquots of the batter were weighed into 50 mL glass centrifuge tubes (i.d. 2.5 cm) and centrifuged at 200 x *g* for 10 min. The centrifuge tubes were stoppered and placed into a 70–75°C water bath to cook for 30 min. Immediately after removal from the water bath, the water and fat exudates were decanted into calibrated conical 15 mL centrifuge tubes for measurement.

The gel remaining in the centrifuge tube was allowed to cool to room temperature. Gel strength was determined by placing the centrifuge tube vertically in a rack placed on the platen of an Instron Universal Testing Machine, forcing a 1/4 in. (0.64 cm) diameter, flat-bottomed rod through the gel at 50mm/min, and recording the maximum force (grams) of the initial penetration.

The salt additions replaced a molar equivalent amount of NaCl. Nonionic compounds replaced an equivalent weight of water to keep protein, fat and salt levels equal. Level of salts were chosen, in part, to minimize resulting pH changes.

Concentrations were calculated based on the aqueous phase of the batter (i.e., 136g). Additions in Table 4 were dissolved in water, neutralized with 0.1M HC1 or NaOH, if necessary, and chilled before incorporation into the batter, unless specifically indicated. Many of these compounds were tested *only* to observe their effects on a meat batter. These experiments *should not* be interpreted to imply safety or legality in food products.

RESULTS & DISCUSSION

THE WATER EXUDATION TEST predicts the batter's loss of water during commercial smokehouse processing (Meyer et al., 1964) and is related to the meat protein's water binding ability. The fat exudation measures the batter's ability to bind and emulsify the fat. Failure to bind fat would result in fat caps during smokehouse processing and excessive fat loss when reheated by the consumer. The penetration force measures the strength of the protein-protein interactions after heat gelation which would be perceived as a frankfurter's firmness.

The effects replacement of NaCl by equivalent molar amount of various salts had on the pH and three functional properties of the meat batter are listed in Table 1. Average values for functional properties of the NaCl controls are typical (Whiting and Miller, 1984; Whiting, 1984, 1987). The pH values are normal for beef and close to the point of batter failure with this salt concentration (Whiting, 1984). Fat exudations were

Table 1 — Effect of selected salts on the functional properties of a meat batter

Salt[a]	M	pH	Water exudate (% batter)	Fat exudate (% batter)	Gel strength (g)
NaCl-Control	0.45	5.59	10.0	0.10	470
NH_4Cl	0.15	5.63	6.0	0.07	530
KCl	0.15	5.65	8.0	0.17	470
LiCl	0.15	5.61	8.0	0.13	550
$MgCl_2$	0.15	5.36	0.0*	0.00	630
$CaCl_2$	0.15	5.33	2.7*	0.00	710*
$CaCl_2$	0.013	5.58	6.3	0.03	540
CuCl	0.014	5.54	19.7*	0.20	490
$ZnCl_2$	0.013	5.43	28.0*	6.60*	430
$FeCl_3$	0.0043	5.44	19.0*	0.70	360
$LaCl_3$	0.0045	5.46	17.3*	0.43	340
$AlCl_3$	0.0044	5.43	19.3*	0.47	390
$SnCl_4$	0.0044	5.31	21.7*	2.00	350
EDTA	0.016	5.41	20.0*	0.57	400
NaBr	0.15	5.63	4.7*	0.10	520
$NaNO_2$	0.15	5.65	8.0	0.07	460
Na_2SO_4	0.013	5.61	6.0	0.07	530
Na_2HPO_4	0.013	5.86*	1.7*	0.03	660
$Na_4P_2O_7$	0.0075	5.77	0.0*	0.00	950*
Na acetate	0.013	5.70	5.0*	0.20	540
Na citrate	0.022	5.78	3.0*	0.10	580

* Means in a column having an asterisk are significant from NaCl control by Dunnett's Test ($p \leq 0.05$)

[a] Salts replace an equal molar quantity of NaCl

generally low in this series, and therefore, only salts which caused detrimental changes in the batter could be identified.

The first set of chloride salts (elements in group IA and IIA of the periodic table and ammonium) were generally equal to or better than the NaCl they replaced. All tended to reduce water exudation and most increased the gel strength relative to the control, although not always significantly. The 0.15M $MgCl_2$ and $CaCl_2$ improved the batter despite decreasing the pH more than 0.2 pH units, a pH change which would be expected to decrease quality or even cause a failure of the batter (Whiting, 1984).

The second set of salts include transition metal chlorides having valences from one to four. These were added in low amounts, replacing very little NaCl, because of their strong ability to lower the pH when the cation binds to the proteins (Whiting and Richards, 1978). Except for stannous chloride, the pH decreases were not greater than with magnesium and calcium chloride in the first set of salts. These metal chlorides were quite detrimental to all three functional properties. Water exudates were generally doubled over the controls. Fat exudations were not as consistent, but addition of zinc caused a large exudation. With such large exudations, gel strengths were not decreased as much as expected, but gels lost their elastic nature and became mushy and mealy.

Addition of disodium EDTA was expected to improve the functional properties by chelating the detrimental metal cations, but the opposite was observed. This form of EDTA did lower the pH but probably it chelated the beneficial and more prevalent magnesium and calcium ions (USDA, 1980).

The last set of additions was sodium salts which tended to raise the pH slightly and decrease the water losses. Phosphates greatly increased the gel strength as well. The beneficial effects of phosphates in meat systems are well documented although the mechanism is still debated. Trout and Schmidt (1984) showed evidence that it was a combination of pH and ionic strength; others (Hamm, 1970) believe phosphates selectively bind to the proteins and increase solubilization and water holding capacity. The sodium sulfate at concentrations equivalent to the sodium orthophosphate did not improve the water binding or gel strength as much. Sodium citrate had a significant beneficial effect on water binding and, to a lessor extent, the gel strength. Its action may be attributed to the increase in pH, increased ionic strength from polyvalency or chelation of cations.

Attempts have been made to fit the effects of ions in meat systems to the Hofmeister series of chaotropic ions (Gortner and Gortner, 1953; Swift and Sulzbacher, 1963, Regenstein, 1984). The Hofmeister series is a ranking based on ability to floculate proteins (Gortner and Gortner, 1953), and this ability may or may not aid binding and gelation depending on the strength of the ion-protein interaction and on the effect of this interaction on protein solubility and aggregation upon heating (Ziegler and Acton, 1984). Wierbicki et al. (1957) found calcium and magnesium chlorides reduced the amount of juice expressed from cooked meat relative to that from sodium chloride or potassium chloride. However, Regenstein (1984) reported the expressible moisture from a cod fish loaf was greater with calcium and magnesium chlorides and showed sodium chloride and iodide to be somewhat better than nitrite or sulfate. Whiting and Richards (1978) found divalent copper and zinc chlorides had a detrimental effect on chicken frankfurters. Polyvalent cations are considered to form salt bridges between adjacent proteins and reduce water binding by tightening the protein matrix. Monovalent copper, however, behaved similarly.

Sodium, potassium, magnesium and calcium chlorides were tested for their batter forming ability when added as the only salt. Table 2 shows results of the four salts at equal ionic strengths. In this series, potassium was poorer ($p \leq 0.05$) than sodium in all three properties. Magnesium was very effective in improving water binding, while calcium was not ($p \leq 0.05$) different from sodium. This reinforces the conclusions drawn from Table 1 and indicates magnesium, calcium and potassium chlorides could functionally substitute for sodium. Cost, flavor and toxicity problems may restrict or prevent their use.

The separate influences of pH and cations were examined (Table 3). The pH of the batters was altered by additions of small amounts to 1N NaOH or HC1 at the beginning of the chopping. Lowering the pH by 0.20 pH units to 5.61 was detrimental to all three functional properties. Adding 0.0043M ferric chloride reduced the pH 0.20 units and had an equally detrimental effect on the functional properties. Addition of ferric chloride and raising the pH 0.20 units back to that of the sodium chloride control only partially restored the water and fat exudates and gel strength. Magnesium chloride appeared to act independently of pH. Batters with an addition of 0.19M magnesium chloride were equal to or better than the controls even with the 0.26 pH units decrease. Raising the pH back to 5.80 did not improve the gel strength of the batter.

Table 2—Functionality of meat batters made with NaCl, KCl, $MgCl_2$ or $CaCl_2$ as the sole added salt

Salt	M	pH	Water exudate (% batter)	Fat exudate (% batter)	Gel strength (g)
NaCl	0.45	5.72	7.3^{b}	0.17^{a}	660^{bc}
KCl	0.45	5.80	10.0^{c}	0.23^{b}	560^{a}
$MgCl_2$	0.15	5.48	2.7^{a}	0.00^{a}	590^{ab}
$CaCl_2$	0.15	5.52	7.0^{b}	0.00^{a}	700^{c}

n = 2

[a-c] Means in a column with different superscripts are significantly different by Duncan's multiple range test ($p \leq 0.05$)

Table 3—Effect of salt and pH on the functionality of meat batters

Salt	Treatment	pH	Water exudate (% batter)	Fat exudate (% batter)	Gel strength (g)
NaCl		5.81^{c}	3.0^{ab}	0.07^{ab}	540^{bc}
NaCl	Reduced pH	5.61^{b}	12.7^{c}	0.27^{bc}	360^{a}
$FeCl_3$		5.60^{b}	11.7^{c}	0.33^{c}	360^{a}
$FeCl_3$	Raised pH	5.83^{c}	5.3^{b}	0.17^{abc}	460^{b}
$MgCl_2$		5.53^{a}	0.3^{a}	0.00^{a}	550c
$MgCl_2$	Raised pH	5.80^{c}	0.0^{a}	0.00^{a}	550^{c}

n = 3

[a-c] Means in a column with different superscripts are significantly different by Duncan's multiple range test ($p \leq 0.05$)

Table 4—Effects of various compounds on the functionality of a meat batter[a]

	pH	Water exudation	Fat exudation	Gel strength
Control	(5.58)	(10.3%)	(0.50%)	(458g)
5% Sucrose	1.00	0.57	0.31	1.06
5% Glycerol	1.00	0.43*	0.53	1.14
6.6% Potato Starch[b]	0.99	0.07*	4.53	1.05
0.25% SDS	1.01	1.17	1.06	0.92
0.25% Triton X-100	1.01	2.36*	15.2*	1.06
0.66% Monoglyceride[b]	1.00	2.16*	22.0*	0.96
0.66% TWEEN 80[b]	1.00	2.96*	54.0*	1.20[d]
0.56% Ethanol	1.00	0.96	1.04	0.89
1.4% Ethanol	1.00	1.06	1.65*	1.03
1.4% Isopropanol	1.00	0.93	1.13	1.29
5% Methanol	1.01	2.11*	6.25*	1.00
0.66% H_2O_2	1.00	1.04	1.36	0.92
0.66% Na Thiosulfate	0.99	0.25*	0.78	1.10
0.25% 2-Mercaptoethanol	1.00	1.11	1.06	0.92
0.1% Na Borohydride[b]	1.14*	0.26*	1.00	1.02
0.4% N-ethylmaleimide[b]	1.00	1.21	1.35	1.05
0.4% Cystine[b]	1.00	0.97	1.41	0.86
5% Dioxan	1.01	0.54	0.81	1.48[c]
4.5% Trifluoroacetic acid	1.01	0.64	0.94	1.42
0.5% Urea	1.00	0.82	0.73	0.98
2.0% Urea	1.01	0.39*	0.27*	1.21
5.0% Urea	1.02*	0.00*	0.00	1.24
0.32% Arginine·HCl[b]	1.00	0.96	0.84	0.90
0.65% Arginine·HCl[b]	1.00	0.89*	0.61*	0.92
1.3% Arginine·HCl[b]	1.02	0.63*	0.36*	0.92
0.25% Na Citrate[b]	1.01	0.72	1.00	1.00
0.50% Na Citrate[b]	1.03*	0.52	1.40	1.41*

[a] Values are ratio of treatment to respective control values. Averages of the control values are in parentheses. *Values in a column with an asterisk are significantly different from their respective control by Dunnett's Test. ($p \leq 0.05$) n = 3 or 4.
[b] Added as powder to batter.
[c] Probability of being the same as the control by Dunnett's test is 0.06.
[d] Mealy texture.

amounts of selected compounds to the batter formulations. Because this table combines a series of experiments made with different batches of meat, the average values for the controls (NaCl only) are given and the values for the treated batches are expressed as the ratio with their respective control. The pH of meat batches varied from 5.3 – 5.9, for example. Within each experimental group, the treated batters were statistically compared to their control by Dunnett's (Steel and Torrie, 1969) test ($p < 0.05$). Although several compounds significantly changed the pH, these changes were small.

Sugars and complex carbohydrates can bind water, stabilize hydrophobic interactions and increase the thermal stability of globular proteins. Sucrose had only a nonsignificant tendency to reduce water and fat exudation. Glycerol significantly decreased the water exudation agreeing with recent findings on frankfurter texture by Lacroix and Castaigner (1985). Potato starch effectively reduced the water exudation. Fat exudations were frequently small in control batters; slightly greater exudations in treatments, therefore, resulted in large ratios even though fat exudation was not excessive.

Nonionic detergents were quite detrimental to the batter. Triton X-100 and TWEEN 80 greatly increased water and fat exudation. The TWEEN 80 gel was very dry and mealy. Van Eerd (1971) used the extracted protein-oil emulsification model to place the HLB values of meat proteins at approximately 14. TWEEN 80 should be a good emulsifier for this HLB value. Van Eerd (1971) found a modest improvement in emulsion stability with it in an oil model system. These data suggested meat batters were more like a gel than an emulsion. An ionic detergent, sodium dodecyl sulfate, did not have a significant effect. The sulfate group may make it too hydrophilic to act as an emulsifier, as sodium laurate was shown to be in the previous paper (Whiting, 1987). The commercial monoglyceride was also detrimental to both water and fat exudations. Honikel (1982) reported brühwurst with mono- or diglycerides or their lactic or citrate esters had only a slight effect on jelly or fat deposits.

Water has a high solvent polarity (Snyder and Kirkland, 1974) with a great ability for dipole interaction and capability to both accept and donate protons. Alcohols reduce the dielectric constant of water and reduce the ability of water to interact with protons. This effect increases with concentration and increasing chain length of the alcohol. They generally act as denaturants to proteins. Methanol (5%) and ethanol (1.4%) were detrimental to the batter's water and fat exudations. Lower ethanol concentrations and 1.4% isopropanol had no effect. Denaturation of the proteins during chopping was detrimental to the meat batter.

Samejima et al. (1981) concluded that the heat-induced gelation requires aggregation of the head portion of myosin by formation of disulfide bonds. Kim et al. (1986) used cystine, Na borohydride and N-ethylmaleimide to indicate a role of sulfhydral groups in fish protein gelation at low temperatures (surimi). In our experiments, disulfide oxidation by H_2O_2, retention of sulfhydryls and reduction of disulfides by mercaptoethanol or blockage of sulfhydryls by N-ethylmaleimide had no effect. Promotion of disulfide interchange by cystine also had no effect. Reducing agents, Na thiosulfate and Na borohydride, significantly reduced water exudation. These are general reducing agents and with an absence of any affect from mercaptoethanol or N-ethylmaleimide likely do not involve the disulfides but instead the general reducing potential of meat. Prerigor and fresh meat have better functionality than stored meat, this data suggesting that the greater reducing potential was a factor.

Dioxane and trifluoroacetic acid (neutralized with NaOH before being added to the batter) have high hydrogen bonding abilities and showed a tendency to improve the water binding and gel strength. Urea solubilizes proteins by disrupting hydrogen bonds and stabilizing hydrophobic and peptide groups. The pH was slightly increased but probably not enough to account for the significantly improved water and fat retention observed with addition of 2 and 5% urea. Arginine at 0.65% and higher reduced fat and water exudations. Its hydrophilic side chain can be involved in electrostatic and hydrogen bond formation. These data suggested the importance of denaturing the suspended-dissolved proteins before initiating the protein-protein interactions that form the gel.

Citrate was found to significantly increase the gel strength and to a lesser extent water binding confirming the observation on Table 1. The 0.5% addition raised the pH slightly in a batch of meat having the lowest pH.

This work suggested several alternatives for improving meat batter when made with reduced sodium chloride. Group IA and IIA cations and phosphate, acetate and citrate anions can partially substitute for NaCl. Solubilities must be considered. Calcium and magnesium salts and phosphates, for example, are not very soluble when added together. Starches and other carbohydrates will reduce water exudation. The feasibility of arginine and urea is unknown; however, Stansby et al. (1968) noted that dogfish, which are used for human consumption, contain more than 1% urea.

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