Stability and Gel Strength of Frankfurter Batters Made with Reduced NaCl

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ABSTRACT

A detailed examination of fat emulsification and water-binding capacities in frankfurter batters and the cooked batters' textural responses to lowered levels of added sodium chloride was conducted. In response surface analyses of water and fat exudations and gel strength with varying compositions of fat, water, meat, and salt, the area of maximum stability decreased and moved toward a higher fat content when the salt was reduced from 2.5 to 1.5%. Gel strength increased with increasing content of lean meat and decreased with lowered salt levels. When salt, pH, chopping temperature, and cooking temperature were varied from the standard conditions, water exudate was generally affected first and most intensely while the gel strength was second. Fat release did not occur until more extreme conditions were encountered.

INTRODUCTION

EPIDEMIOLOGICAL, animal, and human studies strongly suggest that the consumption of sodium by some Americans should be curtailed to reduce the development of high blood pressure and subsequent cardiovascular diseases (Sebranek et al., 1983). Meat products significantly contribute to this dietary sodium. Of the average daily consumption of 10-12g NaCl, approximately 3-4g are added during food manufacture, with about 1g of this from meat products.

The salt concentration affects flavor, microbial shelf life and safety, and texture of meat products. Studies examining various ways to reduce the sodium content of meat products were reviewed recently by Maurer (1983) and Terrell (1983). The approaches generally involved (1) reducing the addition of NaCl, (2) substitution of other chloride salts for NaCl, (3) addition of other ingredients, and/or (4) alteration of processing techniques.

The emulsion characteristics of a frankfurter batter have received considerable emphasis (Webb, 1974; Acton et al., 1983). Salt solubilizes myofibrillar proteins which denature on the surface of the fat particles during comminution to form a stable emulsion. Recognizing the role of other proteins in the viscous colloidal solution that stabilizes the fat droplets, Swasdee et al. (1982) suggested the term "meat batter" to describe the system. More recently, the gelation aspects of the comminuted meat-salt brine-fat system have been studied (Lee et al., 1981). During thermal processing, the batter gels to produce the pseudoplastic solid characteristic of a frankfurter or bologna. This process is also a function of myofibrillar proteins (Acton et al., 1983).

For an effective reduction in the sodium content of frankfurters, the relationship between the meat batter's stability and texture as the sodium chloride content is reduced must be defined. In this report the compositional effects at different salt levels on the water binding ability, fat holding ability, and gel strength are presented. The characteristics of batters made with normal and reduced salt levels were determined under varying conditions of pH, chopping temperature, and cooking temperature.

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MATERIALS & METHODS

Meat

Fresh beef bottom rounds and pork adipose tissues were obtained from local abattoirs or wholesalers. The lean beef was trimmed of fat and gross connective tissue, ground coarsely, and stored at 1°C until used. Samples were analyzed for protein, fat, and moisture contents by the Kjeldahl, Soxhlet, and oven drying methods, respectively (AOAC, 1975). The beef lean and pork fat were further ground separately through a 3/16 in. plate prior to use.

Formulation and processing

The standard batter formulation of 200g contained 106g lean beef, 52g pork adipose tissue, 37g ice, and 5.0g NaCl. When the quantity of water was 40g or less, it was added as −29°C ice. All ingredients were added to the chopping bowl of a food processor (Cuisinart CFP-9) and chopped with brief interruptions to scrape sides of the bowl and measure the temperature until 16.0 ± 0.5°C was reached (Whiting and Miller, 1984).

Two 30 ± 0.1g aliquots of the batter were weighed into 50 mL glass centrifuge tubes (i.d. 2.5 cm) and centrifuged at 50 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 centrifuge tubes for measurement (Morrison et al., 1971). Total exudate was the sum of the water and fat exudates.

The gel remaining in the centrifuge tube was allowed to cool to ambient temperature. Gel strength was determined by placing the tube vertically in a rack placed on the platen of an Instron Universal Testing Machine and forcing a 1/4 in. diameter, flat-bottomed rod through the gel at 500 mm/min. The maximum force of the initial penetration was recorded.

Statistical analyses

Water and fat releases and penetration forces of the two centrifuge tubes from a batter were averaged as one replicate. The effect of batter composition was analyzed by response surface methods (Henika, 1972; Hare, 1974). A second order mathematical model was used to fit the surface to the data.

RESULTS & DISCUSSION

THE STANDARD ADDITION of 2.5% NaCl is representative of the current industry practice for meat emulsion products (Terrell and Brown, 1981). The reduced sodium formulation contained 1.5% NaCl with the 1% reduction of salt compensated by an increased water content. The 2.5 and 1.5% NaCl formulations corresponded to 3.9 and 2.4% brine, respectively. The 1.5% salt level was picked as being an extreme reduction that would still possess frankfurter properties. Based on the proximate analyses, our uncooked standard batters averaged 12.0% protein, 24.3% fat, and 61.4% water. These values are intermediate between red meat and poultry frankfurters (USDA, 1980).

Composition

The composition of the batters was varied to develop response surfaces representing the stability of the batters. The response surfaces were calculated and plotted at both levels of salt by normalizing the lean meat, adipose tissue, and added water content. The three axes represent the percentages of the three major ingredients and sum to 100%

for each formulation. Lean meat varied from 10-90% of the formulation, adipose tissue from 5-60%, added water 5-40%, and salt 1.5-2.5%. Morrison et al. (1971) showed that a meat emulsion made with soybean oil had cook stability only within a limited range of water contents. The 2.5% salt batters (Fig. 1) corroborate their data; high total exudates were found at both low and high water contents. The 3 mL exudate/30g batter was the same criterion used by Morrison et al. (1971) for 90% stability. The response surface was not an ideal fit with 2.5% salt ($R^2 = 0.85$) because the area of minimum exudate was at a higher adipose tissue content than the contour lines indicate. Maximum stability was at 15-25% added water and 48% adipose tissue, which is neither a legal nor a desirable composition. When salt was reduced to 1.5% (Fig. 1), more extract was released from the batter upon cooking and no area on the response surface had less than 3.0 mL exudate ($R^2 = 0.94$) although one data point had 1.8 mL exudate. The standard frankfurter composition with 2.5% salt had 3.2 mL extract/30g; the only compositions made with 1.5% salt that equalled or surpassed this value had 48% adipose tissue.

The response surfaces for water exudate (Fig. 2) show minimal water loss with 15-20% added water and decreasing water loss with increasing fat content. When the salt was reduced the water extract increased over the entire response surface. The R^2 values for the 2.5 and 1.5% salt response surfaces were 0.93 and 0.99, respectively.

The data for fat exudate (Fig. 3) show little or no release until formulations had 48% added adipose tissue, except when added water was 5% of the batter. Even with 1.5% salt, fat release was relatively low at formulations around the standard composition, and the two response surface contours were similar. R^2 values were 0.77 and 0.83 for the 2.5 and 1.5% salt frankfurters, respectively.

The gel strengths (Fig. 4) measured by penetration force were most dependent upon the percentage of lean tissue. The 2.5% salt formulation had a slightly greater penetration force than the 1.5% formulation over the entire response surface. The surfaces were saddle shaped although only one slope fills the area of the frankfurter compositions. R^2 values were both 0.98.

Total chopping time was an approximation of the batter's viscosity and was also highly dependent upon composition. Fig. 5 shows combined data for the 1.5 and 2.5% salt levels ($R^2 = 0.98$); the salt level had relatively little effect on the time needed to reach 16°C. Using −29°C ice in the low water formulations had some effect in making the chopping times more uniform, but times still varied from 25-369 sec. Lowest times were for formulations that had only 5% added water. Times for the standard formulations averaged 84 sec. Hamm (see Acton et al., 1983) reported that viscosity was inversely proportional to the water content and directly proportional to protein and/or fat content.

Salt content

This experiment examined the effect of salt content alone in greater detail. Batters were made with varying salt additions; the added salt replaced an equal weight of water (ice) to keep the total brine constant. The release of water began to increase when the salt levels were less than 2.0% (Fig. 6). The release of fat, however, did not begin until the salt levels were less than 1.0%. The strength of gels did not show a sharp change at any salt level, and decreased

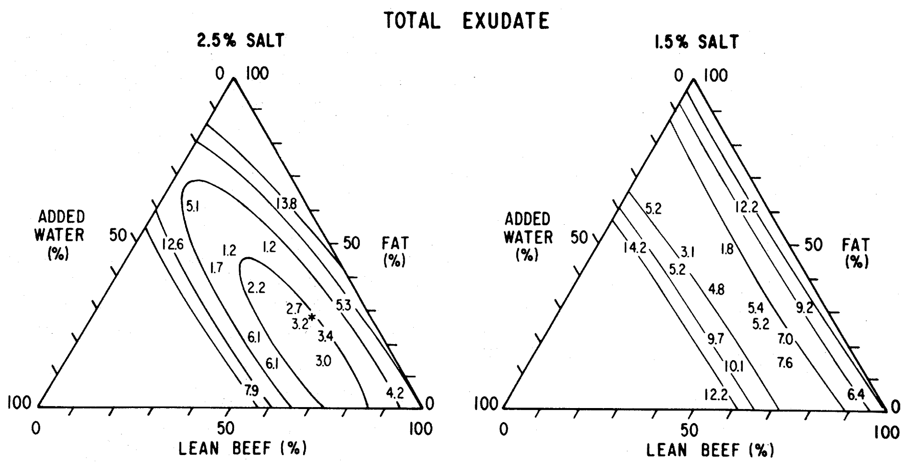

Fig. 1—Response surfaces of total exudates as affected by changes in composition and salt levels. Each number represents the mean of two batters each measured in duplicate. Units are milliliters total exudate per 30g of batter. Contour intervals are 12, 9, 6, and 3 (2.5% salt) mL exudate/30g. The standard composition is marked with an asterisk.

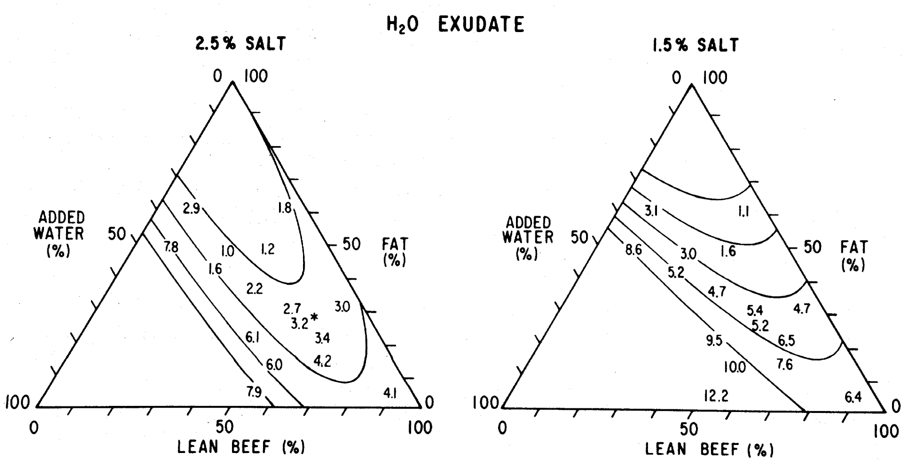

Fig. 2—Response surfaces of water exudates as affected by changes in composition and salt levels. Units are milliliters water exudate per 30g of batter. Contour intervals are 8, 6, 4, 2, and 0 (1.5% salt) mL exudate/30g. Symbols are the same as on Fig. 1.

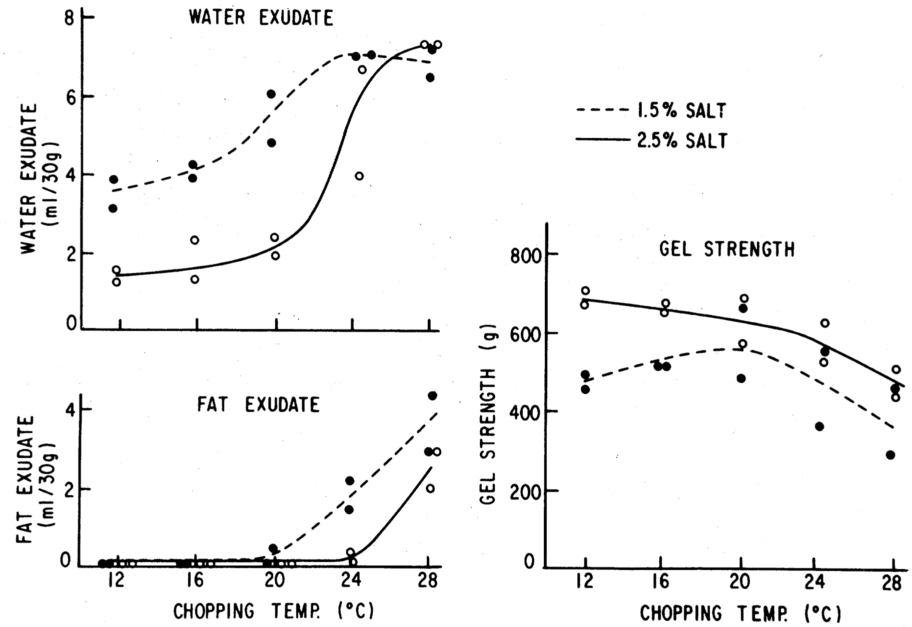

Fig. 8—Water extracts, fat extracts, and gel strengths of batters chopped to differing temperatures. Each point represents a single batter measured in duplicate.

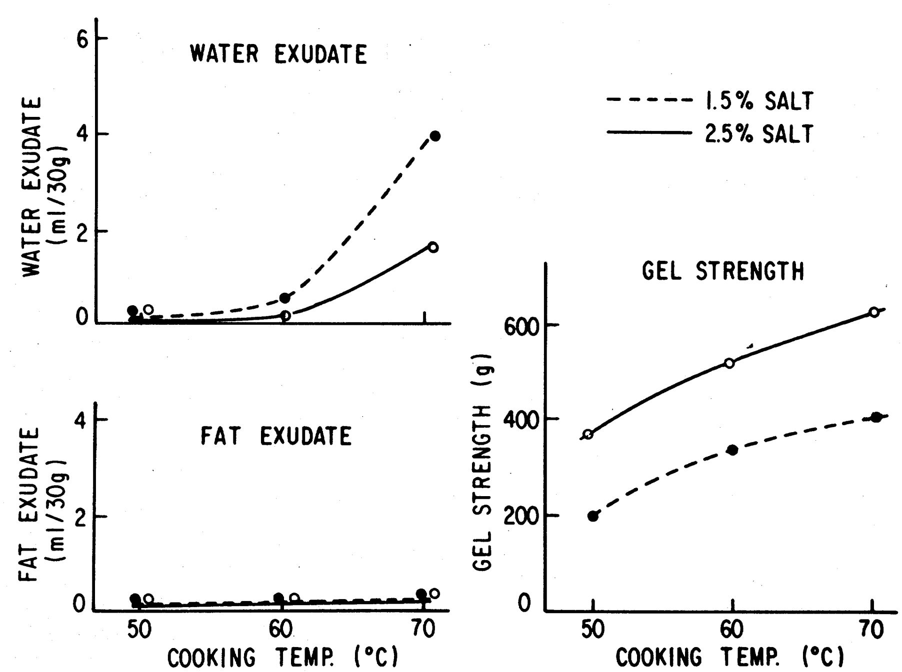

Fig. 9—Water extracts, fat extracts, and gel strengths of batters cooked for 30 min at varying temperatures. Each point represents the mean of four batters, each measured in duplicate.

had greater water losses at 70°C and consistently lower gel strengths than the 2.5% salt batters.

The strength of the gels formed upon heating would primarily be a result of interactions between salt-soluble proteins (Acton et al., 1983). Ishioroshi et al. (1979) found myosin gels reached their maximum shear modulus at 60°C; however, Acton et al. (1981) observed that natural actomyosin gels increased in gel strength from 30-80°C. Siegel and Schmidt (1979) reported myosin binding ability steadily increased from 45-80°C. Lee et al. (1981) found heating of meat emulsions to 70°C reduced the retention of both fat and water relative to 60°C.

In summary, these results of batters with the normal 2.5% salt levels made with the food processor supported the various literature reports. This paper clearly showed the importance of salt in achieving the desirable characteristics and what changes occurred when the salt was reduced. In all experiments, the first attribute of the meat batter to fail with reduced salt alone or with another stress was the water binding. The gel strength was second while the fat emulsification, the traditional point of reference in meat emulsions, was affected least.

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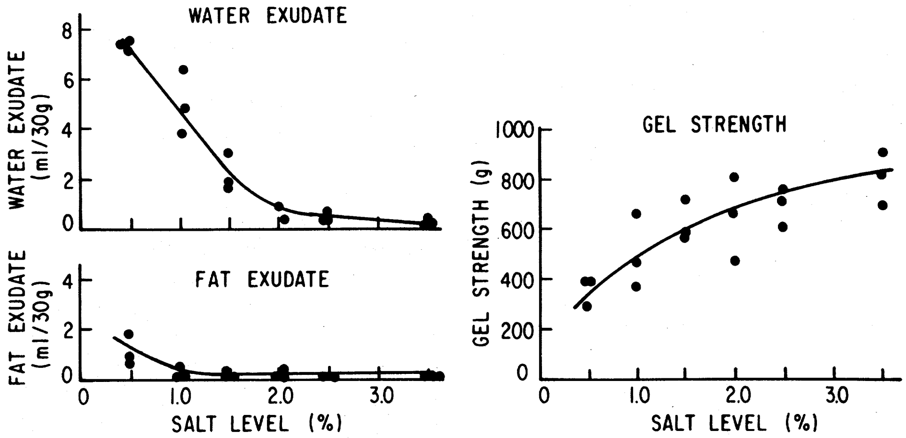

Fig. 6—Water exudates, fat exudates, and gel strengths of batters made with varying salt levels. Each point represents a single batter measured in duplicate.

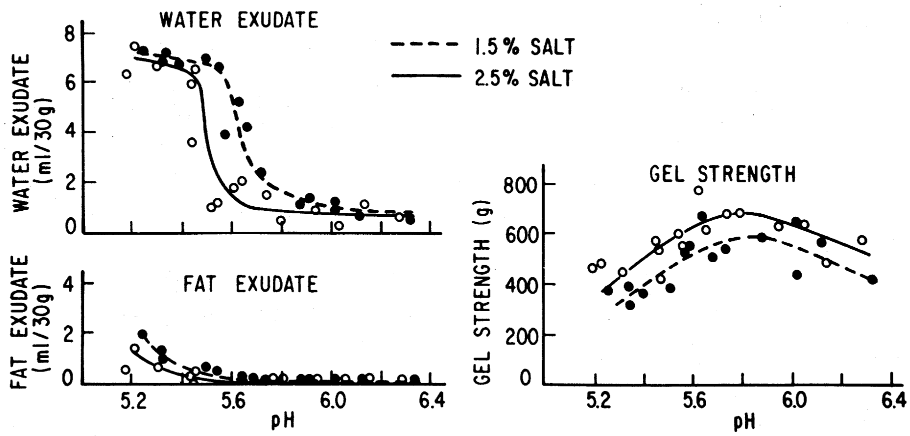

Fig. 7—Water extracts, fat extracts, and gel strengths of batters made with varying pH. Each point represents a single batter measured in duplicate.

ments with protein extracts indicated changing properties when at pH values less than 6. Acton et al. (1981) found natural actomyosin gels had a spongy texture at pH 5.0-5.5 and a uniform and opaque texture at pH 6.0 and above. However, the maximum gel strength occurred with the spongy texture. Gel strengths of purified myosin were maximum at pH 6.0 (Ishioroshi et al., 1979) and the minimum protein concentration for gelation of muscle extracts was at pH 5.8-6.1 (Trautman, 1966). The emulsifying capacity of muscle extracts was lower at pH 5.5 than 6.5 (Whiting and Richards, 1978); however, fat exudation was not apparent in the more concentrated meat batters used in this study.

Chopping temperature

Stability of the batters was greatly affected by chopping temperature as well as salt concentration (Fig. 8). For temperatures from 12-28°C the chopping times varied from 68-249 sec, respectively. Salt concentration did not affect chopping times except at the highest temperatures where 1.5% salt required slightly more time. The water exudate was greater at 12 and 16°C with 1.5% than 2.5% salt and began to increase at a lower temperature with 1.5% salt. The fat exudate likewise began to increase at a lower temperature in the reduced salt batters, 20°C vs 24°C. The penetration forces in the 2.5% salt batters declined slightly as the chopping temperature increased. The penetration forces in the 1.5% salt batters were always less than the 2.5% and declined at chopping temperatures above 20°C.

The temperature where the stability of the batter decreases was shown to be dependent on the characteristics of the fat by Townsend et al. (1968) who found that a phase change in pork fat begins at 18°C which coincided with a loss of emulsion stability. Lee et al. (1981) showed by electron micrographs that fat started to soften and the droplets started to coalesce at 21°C and that fat channels formed at 26°C. However, there is evidence that the proteins have a role in determining the temperature stability and would be expected to show a response to salt levels. The change in emulsion stability between 16 and 22°C was attributed by Jones and Mandigo (1982) to increasing water loss. Deng et al. (1981) ascribed the failure of water binding in a meat batter at 18°C to an increased protein-protein binding at the expense of protein-water interaction, and that fat separation would occur in 2.0% salt batters when chopping temperature exceeded 20°C. Lee et al. (1981) and Jones and Mandigo (1982) defined the comminuted meat batter as a gel-type emulsion where stability depends on the distribution of fat at the beginning of the gel matrix formation and the rigidity of the gel. The increasing stability from a thickening protein film around the fat globule as the chopping temperature increases is opposed by the film becoming too rigid and a loss of integrity of the protein-gel matrix.

The greater losses of water with reduced salt indicate the necessary role of salt for optimal gel formation. However, with 1.5% NaCl the proteins were able to completely bind the fat until temperatures above 20°C were reached.

Cook temperature

Batters of standard composition with either 1.5 or 2.5% salt were cooked for 30 min in water baths at 50, 60, or 70°C. No water or fat exudate occurred at 50°C, but gel strength was low (Fig. 9). Increasing the temperature to 60°C had little effect on water loss but cooking at 70°C increased water loss greatly. There were no fat losses at any temperature. Gel strength, however, steadily increased as the cook temperature increased; values at 70°C were approximately twice those at 50°C. The 1.5% salt batters

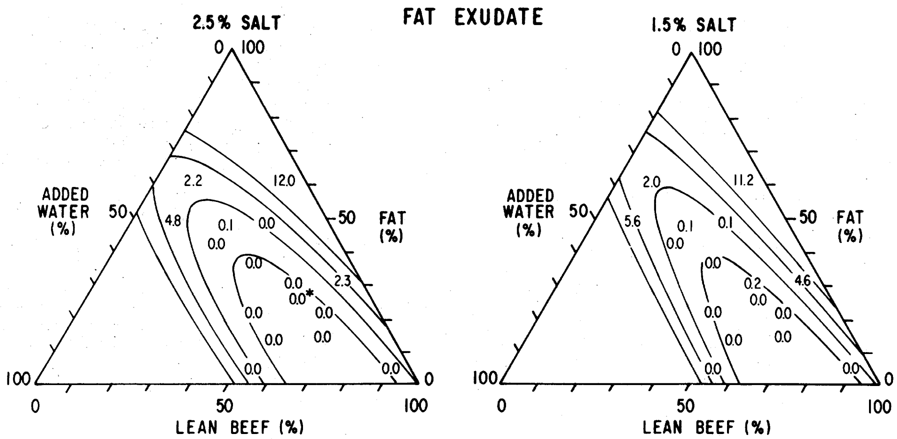

Fig. 3—Response surfaces of fat exudates as affected by changes in composition and salt levels. Units are milliliters fat exudate per 30g of batter. Contour intervals are 6, 4, 2, and 0 mL exudate/30g. Symbols are the same as on Fig. 1.

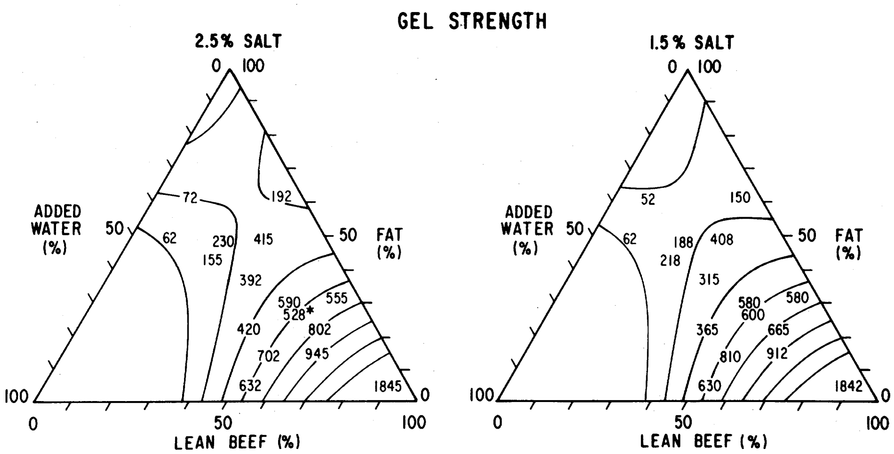

Fig. 4—Response surfaces of gel strengths as affected by changes in composition and salt levels. Units are grams (force). Contour intervals range from 0 - 1400g in steps of 200g. Symbols are the same as on Fig. 1.

with decreasing salt levels over the entire 0.5-3.5% salt range tested. The penetration test had greater variation than the two stability tests in this and subsequent experiments.

These data were in agreement with other kinds of measurements involving salt and meat systems. Swift and Sulzbacher (1963) showed that the emulsifying capacity of a meat slurry increased with increasing salt concentration and this increase was accompanied by an increasing extraction of protein. Shults et al. (1972) showed that water losses from ground beef during cooking decreased as salt content increased. Ishioroshi et al. (1979) reported that although the solubility of purified myosin increases with salt, the gel strength was greatest with 0.2-0.3M salt, depending on the time between extraction and gel formation.

When salt levels were decreased, the water binding ability failed first. The gel strength declined as salt declined but did not abruptly fail at any salt concentration. Fat release did not begin until the water loss had greatly increased and the gel strength had declined about 45%.

pH

The pH of the batters was adjusted from 5.2 to 6.3 by additions of 1M HCl or NaOH after the first 10-15 sec of chopping. The maximum addition to the 200g of batter was 2.5 mL resulting in minimal change in batter composition. The pH was measured at the end of the chopping when the batter reached 16°C by direct insertion of pH electrodes with a temperature compensator.

Batters made with 1.5% salt were more susceptible to breakdown than those made with 2.5% salt (Fig. 7). Again, water exudate was more affected than fat exudate or gel strength. The 1.5% salt batters showed extensive water loss below pH 5.70, whereas the 2.5% salt batters failed at pH 5.55. Fat exudation was not important until the pH was less than 5.4; however, the 1.5% salt batters tended to lose more fat than 2.5% batters. The penetration forces showed that reduced salt gels generally had less strength than the 2.5% gels. Maximum gel strength occurred at approximately pH 5.8; gel strengths declined slightly as the pH increased.

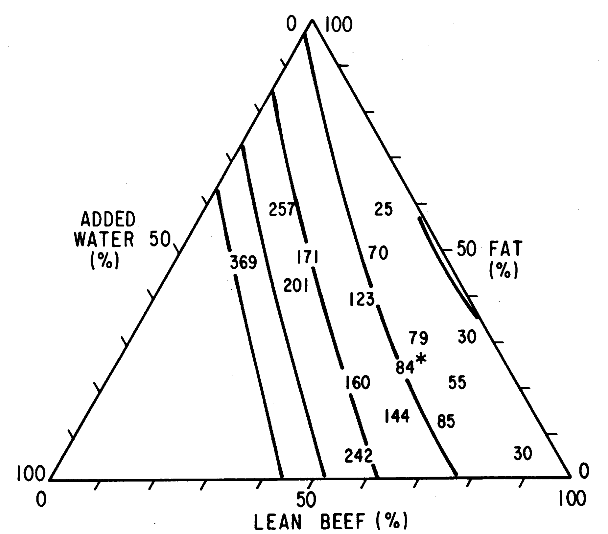

Fig. 5—Response surface of chopping times (sec) as affected by composition. The 1.5% and 2.5% salt levels are combined, each point represents the mean of four batters each measured in duplicate. The standard composition is marked with an asterisk. Contour intervals are 360, 270, 180, 90, and 0.

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