Five control and 5 test dishes (5 replicates) were prepared for each oil. The number of feeding punctures/bud was counted under a dissecting microscope.

RESULTS AND DISCUSSION

Table I gives the plant name and family, oil yield and its content of conjugated acid, and the antifeedant test results for each of the 12 candidate oils tested. Besides tung oil, only the seed oils of *Calendula suffruticosa*, *Centranthus macrosiphon*, *Jacaranda mimosifolia* and *Momordica cochinchinensis* deterred feeding by the boll weevil. Of the latter 4 oils, *C. macrosiphon* was the most effective; this is not surprising, since the seed oil of this plant is known to contain α-eleostearic acid (4). The 9E,11Z,13Z isomer of this acid is present in the seed oils of *Punica granatum* (5), *M. cochinchinensis* (6) and *Trichosanthes anguina* (7) in both the free and combined forms, but only the oil of *M. cochinchinensis* was deterrent. *C. bignonioides* seed oil, which contains the 9E,11E,13Z isomer (5), was ineffective. The active seed oils of *C. suffruticosa* and *J. mimosifolia* contain the 8E,10E,12Z and 8Z,10E,12Z isomers, respectively, of 8,10,12-octadecatrienoic acid (8,9), but the oil of *Calendula arvensis*, which also contains the 8E,10E,12Z isomer (8), did not deter feeding. The seed oils of *Impatiens balsamina* and *I. flemingii*, both of which failed to deter feeding, contain (9Z,11E,13E,15Z)-9,11,13,15-octadecatetraenoic acid (10). *Santaium album* seed oil, which was also ineffective, is known to contain (E)-11-octadecen-9-ynoic acid (11). All conjugated acids were found to be unisomerized.

ACKNOWLEDGMENTS

C. Harding and S.B. Haught provided technical assistance.

REFERENCES

1. Jacobson, M., M.M. Crystal and J.D. Warthen, Jr., J. Agric. Food Chem. 29:591 (1981).
2. Hardee, D.D., and T.B. Davich, J. Econ. Entomol. 59:1267 (1966).
3. Jacobson, M., U.S. Patent Appl. 140,911 (Apr. 16, 1980).
4. Hopkins, C.Y., and M.J. Chisholm, Can. J. Chem. 43:3160 (1965).
5. Privett, O.S., in "Progress in the Chemistry of Fats and Other Lipids," Vol. IX, part 3, edited by R.T. Holman, Pergamon Press, Oxford, 1968, pp. 409-452.
6. Airan, J.W., and S.V. Shah, J. Univ. Bombay 11:105 (1942).
7. Crombie, L., and A.G. Jacklin, J. Chem. Soc. 1632 (1957).
8. Chisholm, M.J., and C.Y. Hopkins, Can. J. Chem. 38:2500 (1960).
9. Chisholm, M.J., and C.Y. Hopkins, J. Org. Chem. 27:3137 (1962).
10. Takagi, T., JAOCS 43:249 (1966).
11. Hatt, H.H., and A.Z. Szumer, Chem. Ind. 962 (1954).

[Received March 5, 1981]

Effect of Plastic Fats on Thermal Stability and Mechanical Properties of Fat-Protein Gel Products

C.M. LEE, J.W. HAMPSON[1] **and A. ABDOLLAHI**, Department of
Food Science & Technology, Nutrition and Dietetics,
University of Rhode Island, Kingston, RI 02881

ABSTRACT

Meat was comminuted with soybean-oil-based plastic fats of different physical properties and cooked at 2 different rates. Thermal stability of emulsion was inversely related to fat softness and heating rate. Stable emulsions were obtained when prepared with fat containing 30% solids at 16% product fat level, 40% solids at 22% level, and 50% solids at 28% level. Release of fat and water upon heating commenced about 10 C below the softening point of the fat. Compressive force (CF) increased markedly and shear force (SF) increased moderately with increasing hardness of fat. Both CF and SF reached a maximum at the 40% fat solids level. Increased total fat tended to reduce mechanical strength. Faster heating resulted in greater mechanical strength of cooked product but caused fat separation in high fat products formulated with soft fats.

INTRODUCTION

Comminuted meat products such as frankfurters and sausages are prepared by chopping meat with the addition of salt and ice to a fine homogenate which forms a stable matrix upon cooking. When the temperature of the comminuted batter reaches the melting point of the fat incorporated during chopping (1), or a flowing of fat is allowed within the matrix, the fat starts to coalesce, resulting in emulsion destabilization. A formation of large conglomerates of fat accompanied with discontinuity of protein matrix was seen photomicrographically in the batter chopped at 26 C, whereas uniform fat dispersion in a continuous protein matrix was observed in batter chopped at 16 C (2,3). Interestingly, after being cooled to 17 C by adding Dry Ice while chopping, such destabilized emulsions (chopping temperature 27 C) were restabilized (4). A recent study by Lee et al. (3) explained stabilization after addition of Dry Ice by hardening of fat which permits uniform fat distribution. This clearly indicates that emulsion stability is determined by the fat distribution pattern which, in turn, is influenced by the physical state of the fat incorporated at the time of comminution. Despite the seemingly important role of fat physical properties in emulsion stabilization, virtually no studies have been reported, particularly in relation to stability of protein-gel type emulsions. Therefore, it was decided to investigate how physical properties of fats affect the emulsion stability as well as the mechanical properties of cooked emulsion products. Parameters used in this study were physical properties of fat, thermal stability of emulsions and mechanical properties of cooked products.

MATERIALS AND METHODS

Preparation of Plastic Fats and Emulsions

Soybean-oil-based plastic fats were prepared by melting an 800-g mixture of soybean oil (IV = 120) and stearin (mp =

---

[1] Eastern Regional Research Center, SEA, USDA, Philadelphia, PA 19118.

70 C) (Durkee Foods, SCM Corp., Cleveland, OH) in a water bath at 70 C such that the DSC-measured solid fat content was varied from 10 to 50%, and subsequently solidifying under constant mixing in an ice-water bath to permit uniform crystallization. IV and mp were determined by Wijs (5) and Capillary tube (6) methods, respectively. The mixing time varied, depending on the time required for complete crystallization which was different from batch to batch.

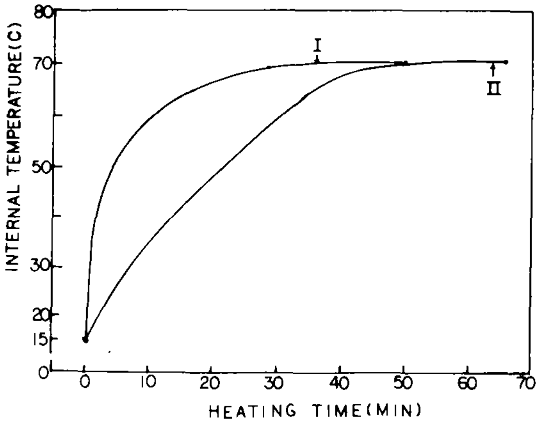

FIG. 1. Heating curves of fast heating (I) and slow heating (II).

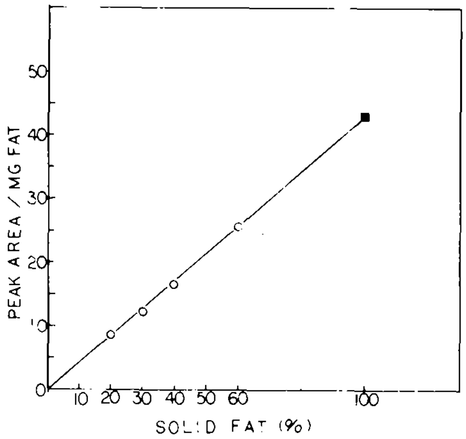

FIG. 2. Relationship of solid fat contents to the area of endothermic peak. ■ Soy stearin; ○ plastic fat.

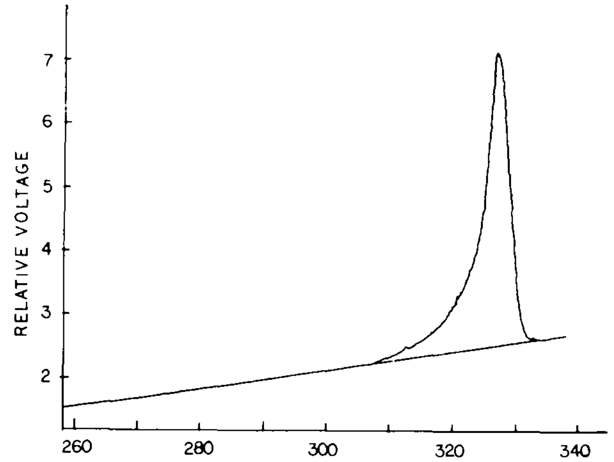

FIG. 3. A typical computer output of endothermic peak.

Meat emulsions were prepared by chopping 600 g of prechilled ground meat (0 C, 3.2% fat) with 262 mL of 10.25% NaCl solution (0 C) and 35 mL of 50% corn syrup (DE42, Clinton Corn Processing Co., Clinton) in a 5-pound capacity Fleetwood bowl chopper (Model FC-14) for 15 min. Individual batters were further chopped, respectively, after addition of 145 (16%), 225 (22%), and 350 g (28%) of plastic fats of different physical properties for another 15 min. Each batter was stuffed into cellulose casings (23 mm diam., Precision Nojax, Union Carbide Corp.), linked into 5-in. pieces and cooked at 2 different rates in a smokehouse equipped with temperature and humidity controls. The heating rate (Fig. 1) was varied by appropriately changing air temperature while maintaining humidity at an average of 40% RH.

Measurement of Viscosity

A Brookfield Viscometer (Model RVT) with a spindle #7 measured the apparent viscosity of the batters at the completion of chopping (18 C). Triplicate measurements were made at 10, 20 and 50 rpm. Shear stress (τ, dyne/cm^2) at the wall of spindle was computed using the following equation: $\tau = (F \cdot M)/(R^2 \cdot 2\pi L)$, where F = full torque capacity (7,187 dyne-cm); M = torque readings (%), R = radius of spindle; and, L = height of spindle.

Shear rate ($\dot{\gamma}$, sec^{-1}) was calculated using the equation, $\dot{\gamma} = 2\pi R \cdot RPS/\delta$ where RPS = revolution/sec, and δ = thickness of the batter involved in shearing action. The apparent viscosity (μ, poise) at a given rotational speed was then computed using the equation, $\mu = \tau/\dot{\gamma}$.

Evaluation of Physical Properties of Fat

A series of fats prepared as above was analyzed for its solid fat content, hardness and softening point. Using a differential scanning calorimeter (Perkin-Elmer, DSC-1B), solid fat content was determined by comparing the peak area (mcal) to that of 100% solid stearin (Fig. 2). The sample weighing ca. 15 mg was cooled to -15 C and heated at increments of 10 C/min. A typical computer output of endothermic peak is shown in Figure 3. Fat hardness was evaluted both by the AOCS penetration method (7) using a micropenetrometer and by the Instron penetration method which was developed in this study. Fat sample was hand-packed in a 100-mL plastic cup with even surface and temperated overnight at 15 C prior to test.

In the Instron penetration method, using a probe of 1.5 mm diameter and a crosshead speed of 50 mm/min and a chart speed of 100 mm/min, the first peak height was determined as the penetration force (Fig. 4). In the AOCS method, the reciprocal of penetration distance measured by the micropenetrometer was used as an index of hardness and termed "hardness index." The softening point was measured by a Fisher-Johns melting point apparatus. Fat samples weighing ca. 10 mg were placed on the plate which

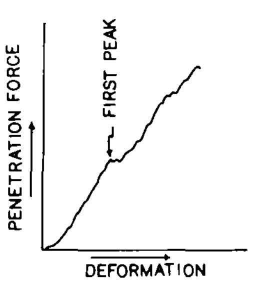

FIG. 4. A typical force-deformation curve obtained by the Instron penetration method.

had been equilibrated at 0 C, and covered with a cover glass. The plate was then heated at increments of 5 C/min. The temperature at which the fat started to flow was read and designated "softening point."

Using the above physical data, relationships among hardness index, penetration force, solid fat content and softening point were obtained.

Thermal Stability Test

Uncooked emulsions were evaluated for thermal stability by the following methods: a plug of batter (ca. 20 g) obtained from each preparation was placed in a 60 mL glass jar and heated at 60 and 70 C, respectively, for 30 min in a water bath. The amount of fat and water released upon heating was measured by transferring the fluid into a 10-mL graduated cylinder. The percentage retention of fat and water was used as an index of thermal stability. Moisture content was determined by the AOAC method (8). Fat content was determined by following the method of Bligh and Dyer (9), except that 100% chloroform instead of a chloroform/methanol mixture (1:2, v/v) was used as an extraction solvent. Also, the internal temperature of the batter at which a release of fluid commenced was determined. The method was as follows: about 20 g of batter was placed in a water-jacketed funnel. A thermocouple probe (copper-constantan) was then placed in the center of the batter. Temperature of the batter was monitored while circulating heated water (60 or 70 C) through the jacket.

Evaluation of Mechanical Properties

Mechanical properties of cooked emulsion products were evaluted by compression and shear tests. Measurements in 5 replications were made with an Instron Testing machine (Model 1122) using cylindrical specimens (20 mm height x 20 mm diam.) at a cross-head speed of 50 mm/min and a chart speed of 100 mm/min. For a single compression testing, 3 different cross-head speeds, 20, 50 and 100 mm/min, were used to evaluate the effect of deformation rate. From a single compression (70% deformation), a force which causes specimens to fail was measured as compressive force, whereas from 3 repeated compressions (30% deformation), unrecoverable deformation was measured and expressed in terms of percentage of plastic deformation (= 100 x unrecoverable deformation/specimen height).

Statistical Analysis of Data

The data were analyzed for the significance of differences between treatments by Student's t-test using the Statistical Analysis System (10).

RESULTS AND DISCUSSION

When the fat hardness index (HI) was obtained as a reciprocal of penetration distance, HI was shown to be an exponential function with respect to solid fat content (Fig. 5), while having a linear relationship to penetration force. The relationship was expressed as: $Y = 14.58\ X - 0.21$, where Y = penetration force (G) and X = hardness index (cm^{-1}). The softening point of plastic fats showed a linear relationship with solid fat content. The relationship was expressed as $Y = 0.327X + 44$, where Y = softening point (C) and X = solid fat content (%).

Emulsion retention of fat was significantly decreased as the fat level or heating rate was increased (Fig. 6). The decreases in retention appeared to be drastic when the emulsions were prepared with soft fat of HI less than 0.54 cm^{-1} (equivalent to 20% solid fat contents). A reduced retention with increased heating rate may explain why emulsions become less thermally stable when cooked at a

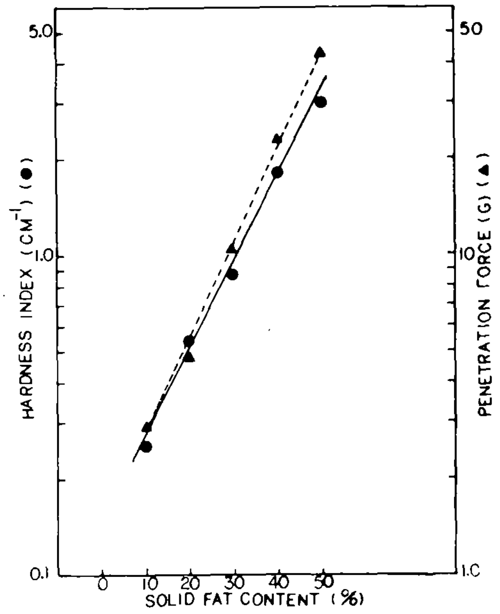

FIG. 5. Relationship of solid fat content + hardness index and penetration force; $Y = (0.136) + (1.064)^X$, where Y = hardness index and X = solid fat content, hardness index = (penetration distance)$^{-1}$.

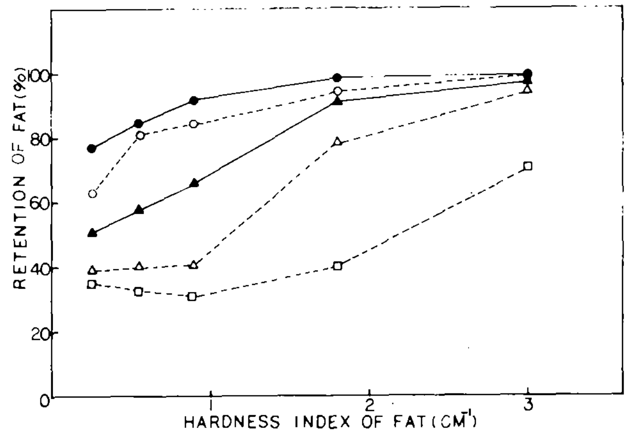

FIG. 6. Effect of fat hardness on the fat retention of emulsions: ●— 60 C, ○--- 70 C (16% fat level); ▲— 60 C, △--- 70 C (22% fat level); and □--- 70 C (28% fat level).

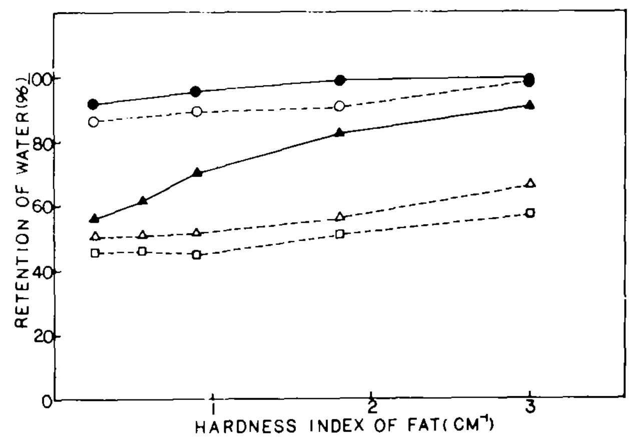

FIG. 7. Effect of fat hardness on the water retention of emulsions: ●— 60 C, ○--- 70 C (16% fat level); ▲— 60 C, △--- 70 C (22% fat level); and □--- 70 C (28% fat level).

high humidity which increases heating rate. In the same figure, fat retention with increasing hardness was smaller at the 16% fat level than at 27 and 28% fat levels. Stable emulsions were obtained with fats of HI greater than 0.87 cm^{-1} (equivalent to 30% solid fat content) at the 16% fat level, 1.8 cm^{-1} (equivalent to 40% solid fat content) at the 22% fat level, and 3.0 cm^{-1} (equivalent to 50% solid fat content) at the 28% fat level.

As shown in Figure 7, water retention was decreased as the fat level was increased. This could be explained by a reduced water retention capacity accompanied by a diminished continuity of gel matrix as a result of an increase in fat level. It was notable that the effect of fat hardness on water retention appeared to be insignificant ($p < 0.05$) at all fat levels except the 22% fat level (60 C).

Figure 8 shows relationships between emulsion solid fat content and the commencing temperature, and between softening point and commencing temperature. The temperature at which a separation of fat and water commenced increased with an increase in solid fat content. This suggests that emulsions prepared with fats of low solid content (soft fats) are thermally less stable unless fat is dispersed uniformly throughout the matrix. Our photomicrographical study (3) revealed that soft fats (0.25-0.54 cm^{-1} HI) were not uniformly dispersed during comminution whereas medium hard fats (0.87-1.8 cm^{-1} HI) were uniformly dispersed. Release of fat and water upon heating emulsions commenced about 10 C below the softening point of fat. Overall, the commencing temperatures at the 16% fat level were higher than those at the 22% fat level, although the difference was not statistically significant ($p < 0.05$).

Changes in emulsion viscosity were rather sharp with an increase in fat hardness up to 0.78 cm^{-1} HI and thereafter remained stable (Fig. 9). This suggests that there is a critical viscosity and hardness index below which emulsions becomes unstable. From the same results, it was also noticed that the viscosity dependency of thermal stability was affected by fat hardness. A photomicrographic study indicated that a soft fat of 0.25 cm^{-1} HI (equivalent to the 10% fat solid level) produced a loose matrix in which fat flowed without being uniformly dispersed, whereas medium hard and hard fats (HI > 0.78 cm^{-1}) were localized in a discrete phase.

Effect of solid fat content on the compressive force of cooked products is shown in Figure 10. With an increase in solid fat content, compressive forces were increased and reached a maximum at the 40% (equivalent to 1.8 cm^{-1} HI) and then leveled off. Leveling off at 40% solid fat content was believed to be due to insufficient fat dispersion which was caused by the decreased mobility of hard fats.

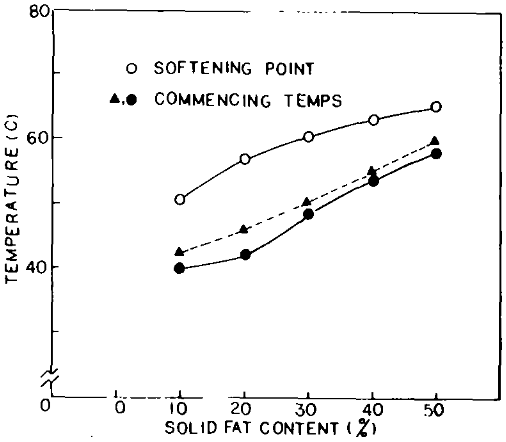

FIG. 8. Relationships of emulsion solid fat content to fat softening point and commencing temperature: ▲ 16% fat level, and ● 22% fat level.

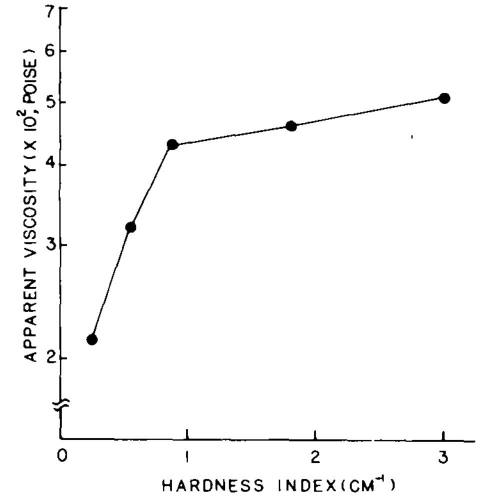

FIG. 9. Effect of fat hardness on the apparent viscosity of emulsions; emulsions were prepared at 16% fat level, and the viscosity was measured at 20 rpm.

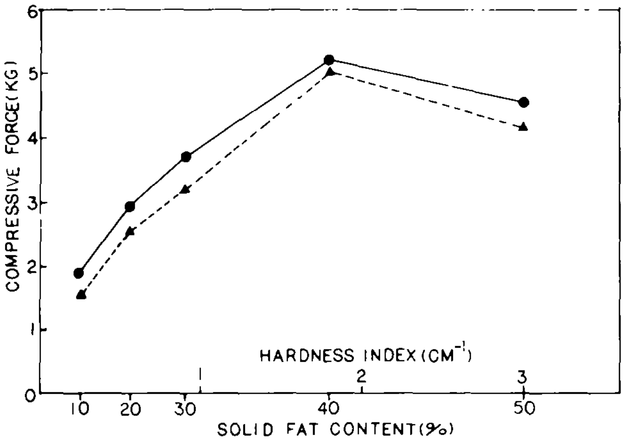

FIG. 10. Effect of fat hardness on the compressive force of cooked products; ● — (fast heating) and ▲--- (slow heating), both at 22% fat level.

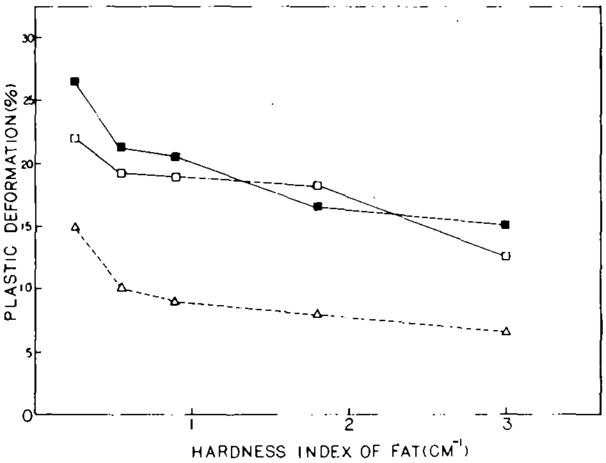

FIG. 11. Effect of fat hardness on the plastic deformation of cooked products; △--- slow heating (16% fat level), □ — slow heating (22% fat level), and ■ — fast heating (22% fat level).

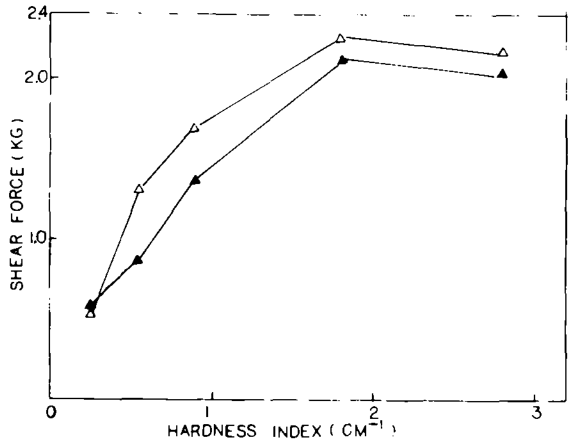

FIG. 12. Effect of fat hardness on the shear force of cooked products; △ --- (slow heating), ▲— (fast heating), both at 22% fat level.

The effect of solid fat content on the compressive force was significant ($p < 0.01$) between the 18% and the 22% fat level, but no significant difference was observed between the 15% and the 22% fat level. No significant difference in compressive forces was observed at 3 different deformation rates (20, 50 and 100 mm/min) ($p < 0.05$). In the same figure, with solid fat contents of less than 20% (equivalent to 0.54 cm^{-1} HI) virtually no compression failure occurred to the products. This was because the matrix was completely disintegrated as a result of fat separation and thus no longer elastic. A complete discontinuity of matrix was shown by a previous photomicrographical study (3). Fast heating resulted in greater product compressive force (Fig. 10) than slow heating.

In Figure 11, the effect of fat hardness on cooked product plastic deformation is shown. At a hardness index greater than 0.54 cm^{-1}, there were insignificant changes in plastic deformation, whereas at HI less than 0.54 cm^{-1}, there were drastic increases in plastic deformation showing no resiliency. With a decrease in the fat level or an increase in the hardness of fats, the continuity of protein matrix was increased. This was reflected in a decrease in plastic deformation. Fast heating resulted not only in greater compressive force but also in greater plastic deformation than slow heating, suggesting that fast heating makes products less brittle or less likely to crack. Shear test results (Fig. 12) showed a pattern of changes in force with changes in solid fat content similar to the compression test.

ACKNOWLEDGMENTS

Presented at the ISF-AOCS Congress, New York, NY, April 27-May 1, 1980.

This work was supported by the NSF Particulate and Multiphase Processes Program (Grant No. CPE-7911293). Rhode Island Agricultural Experiment Station Contribution no. 1993.

The authors thank the Eastern Regional Research Center, Philadelphia, for collaboration and also Durkee Foods and Clinton Corn Processing Co. for providing materials.

REFERENCES

1. Townsend, W.Z., L.P. Witnauer, J.A. Riloff and C.E. Swift, Food Technol. 22:319 (1968).
2. Hansen, L.J., Ibid. 14:565 (1960).
3. Lee, C.M., R.J. Carroll and A. Abdollahi, J. Food Sci. (in press).
4. Helmer, R.L., and R.L. Saffle, Food Technol. 17:1195 (1963).
5. Iodine Value-Wijs Method, "Official and Tentative Methods of the Am. Oil Chem. Soc.," AOCS, Chicago, IL, 1956, Method Cd 16-60.
6. Melting point–Capillary Tube Method, Ibid. Cc 1-25 (1978).
7. Consistency-Penetration Method, Ibid. Cc 16-60 (1973).
8. "AOAC Methods of Analysis," 12th Edn., Association of Official Analytical Chemists, Washington, DC, 1925.
9. Bligh, E.G., and W.J. Dyer, Can. J. Biochem. Physiol. 37:911 (1959).
10. Statistical Analysis System, SAS User's Guide (1979 Edn.), SAS Institute Inc., Cary, NC, 1979.

[Received February 17, 1981]