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Prediction of meat emulsion stability using reflection photometry

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Abstract

Manufacture of finely comminuted meat products are operations that require improved control to produce stable products. Emulsion breakdown becomes evident during the cooking process, when it is too late for corrective actions. Two different emulsion formulations that produced high or low cooking loss tendencies were prepared. Emulsion ingredients were chopped and the mixture was sampled at different time intervals. CIELAB coordinates of each sample were measured and the samples cooked to determine cooking loss and gel firmness. L^* values increased at the beginning of chopping, which was accompanied with increased gel firmness ($P < 0.01$) and reduced cooking loss ($P < 0.001$). After 8 min of chopping (emulsion temperature $\geqslant 22$ °C) a reduction in L^* and b^* values and in emulsion firmness was observed simultaneously with increasing cooking losses. These results suggest the feasibility of an on-line optical sensor technology to predict the optimum endpoint of emulsification in the manufacture of finely comminuted meat products.

Keywords: Light reflectance; Monitoring; Process control; Emulsion stability; Cooking losses; Gel firmness

1. Introduction

Meat emulsions are finely comminuted meat mixtures composed of water, protein, fat, salt and small amounts of other ingredients. These products (e.g., frankfurters and bologna) are an important part of diet in developed nations like the US where meat consumption per capita was 83 kg in 2004 (USDA, 2005). Chopping is one of the most important steps in meat emulsions manufacturing. During this process, the raw materials are extensively comminuted in a bowl chopper in order to reduce the size of the particles and obtain a stable and homogeneous emulsion. At the latest stage of the cooking process, when the temperature reaches 70–75 °C, fat tends to melt and expand (Townsend, Witnaur, Riloff, & Swift, 1968), collagen is transformed into liquid-like gelatin and myofibrillar proteins coagulate (Samejima, Takahashi, & Yasui, 1976) causing a significant reduction in the water-holding capacity of proteins (Shults, Russell, & Wierbicki, 1972). Salt soluble protein denaturation after cooking turns the emulsion into a viscoelastic gel matrix (Xiong, 1997, Ch. 12).

Meat proteins serve as the natural emulsifying agent in a meat emulsion. To form a stable meat emulsion, these proteins must surround the finely chopped fat particles before cooking. Myosin is the most important of the proteins for fat emulsification and water holding capacity of processed meats that may bridge the oil–water interface during the emulsification steps (Xiong, 2000, Ch. 2). Thus, as fat particle size decreases during chopping the emulsion stability will increase, provided there is sufficient protein to coat all the fat particles. As chopping continues, emulsion temperature increase causes the surface tension of the fat particles to decrease. This decrease in surface tension further enhances the particle reduction process and rapidly

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increases the surface area of the fat particles, and, consequently, more protein is required to surround the fat globules. According to Foegeding, Lanier, and Hultin (2000), improving fat coating of comminuted products, usually requires starch and non-meat proteins addition to enhance the textural properties of the products. Starch gelatinizes during cooking, increasing the emulsion viscosity and reducing fat globule mobility. Increasing the proportion of lean tissue would allow more myofibrillar proteins to be extracted to serve as emulsifier.

Obtaining an optimum, stable meat emulsion depends on many factors (Fig. 1) and requires, (a) reducing fat and meat particle sizes, (b) extracting and dispersing the myofibrilar proteins from the cellular structures, and (c) keeping the degree of myofibrilar proteins denaturation to a minimum during chopping to ensure optimum coating of the fat globules with proteins before cooking. These three main requirements for optimum emulsion stability directly depend on the chopping process and impact the final product yield and quality (Allais, Christophe, Pierre, & Dufour, 2004; Jones & Mandigo, 1982). Provided optimum emulsion stability, a high quality finely comminuted meat product would also require adequate gelation of myofibrillar proteins during cooking. If the meat emulsion is unstable, larger fat and water separation will occur during cooking. Increased water and fat separation will reduce both yield and quality of the final product promoting economical losses and consumer rejection. Chopping duration has an optimum where stability of the product is maximized (Girard, 1981) and the separation of water and fat during the cooking process is minimized. Under-chopping usually results in minimal binding of fat particles while over-chopping results in massive fat and water separation during the cooking process. Indeed, obtaining a stable emulsion requires improved control of the emulsification process as a result of the lack of warning signs for emulsion breakdown during chopping (Barbut, 1998). Currently, there is no effective technology to select the optimum chopping duration during meat emulsion manufacturing. Barbut (1998) showed that the Hunter L^* value (lightness) changed during the comminuting process and was correlated to meat emulsion stability during cooking. This finding suggests the feasibility of an optical sensor technology for emulsion control. There is limited information on the correlation between the color indexes (L^*, a^* and b^*) and the meat emulsion metrics (cooking loss and gel strength). Identification of such correlations is needed to investigate the potential use of on-line fiber optic probes to control the chopping process and detect early signs of meat emulsion breakdown (Barbut, 1998). Some studies have been made to measure stability of meat emulsions with conductimetry but rarely to control of chopping process (Curt, 1995). Enhancing meat processing efficiency and flexibility would require the development and application of on-line sensor technologies for real time evaluation of changes occurring in raw materials and final products during meat processing. Such real-time evaluation can provide feedback/forward control for different operations, i.e., activation/deactivation of automatic mechanisms, implementation of alarm systems and application of corrective procedures.

The objective of this study was to determine if CIELAB color indexes measured during the comminuting process can be used to predict cooking losses and gel strength over a range of emulsion stabilities obtained by combining factors such us fat/protein ratio and starch levels.

2. Materials and methods

2.1. Experimental design

A range of emulsion breakdown tendencies were obtained by combining two independent variables: fat/lean ratio and starch concentration in different proportions. Raw material were weighted and premixed according to two different formulas (F_1 and F_2) to obtain two emulsions

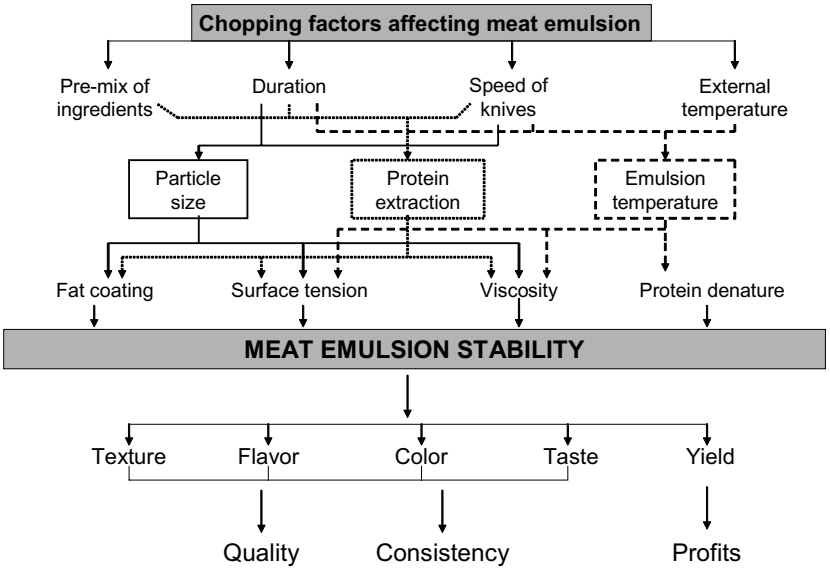

Fig. 1. Principal chopping factors affecting meat emulsion stability.

types exhibiting markedly different breakdown tendencies. "High stability" emulsions, F_1, had a fat/lean ratio of 20–80 and a starch concentration of 5%. "Low stability" emulsions, F_2, had a fat/lean ratio of 30–70 and no starch (Table 1). Each formula was used to manufacture two emulsions under identical conditions (replicates). For each batch, two emulsion samples were taken at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14 and 16 min time intervals to determine two emulsion quality indexes (technological dependent variables): gel strength (G_s) and cooking losses (C_{loss}). The optical changes in the emulsion during chopping were monitored using reflection photometry to evaluate if G_s and C_{loss} could be predicted using CIELAB color coordinates (optical dependent variables).

2.2. Sample preparation

Fresh pork lean and backfat were obtained from a local industrial slaughterhouse. Meat was trimmed for visible connective tissue and grounded together with the fat into small size pieces. Raw materials and other ingredients were weighted in a balance (Sartorious BP 1200, Germany), according to the two different formulas (F_1 and F_2) as describe in the experimental design section. The raw materials, with the appropriate fat/lean ratio, were packed into individual plastics bags and frozen (−18 °C) until use within a period of 2 months. The premixed non-meat ingredients, with the appropriate starch concentration, were packed and stored at room temperature until use. The day before emulsion preparation, raw meat mixtures were thawed overnight in a refrigerator at 4 °C until the sample was at ~0 °C. After mixing the non-meat ingredients for 30 s at low speed (300 rpm), meat and fat were added to the bowl chopper (Robot Coupe, Mod. R 5 V.V., France) and all the ingredients were chopped for 16 min at high speed (1.500 rpm). The chopping process was performed in a pilot plant at ~18 °C of temperature. The emulsion temperature was monitored by inserting a probe model TM 65 (Digital thermometer, Crison Instruments, S.A. Barcelona, Spain) into the emulsion mass every time that an emulsion sample was collected from the bowl chopper.

2.3. Color measurement

The color measurement of each sample was assessed using a hand held chromameter (Minolta Chromameter II CR-200 Reflectance, Minolta Camera Co., Osaka, Japan). The measurements were recorded in Hunter L^* value (lightness) and chromaticity coordinates a^* (redness/greenness) and b^* (yellowness/blueness). The color measurements were performed using a CIE standard 'C' illuminant, an observation angle of 0° and an 8 mm diameter measuring area. The chromameter was calibrated for light source index setting 'C' before color measurements were taken.

Table 1
Proportion of raw products used in the production of two different emulsion types exhibiting different breakdown tendency

Emulsion	Composition (g)						Breakdown tendency
	Lean	Fat	Ice	Salt	Additives	Starch	
F_1-High stability	1125	300	75	37.5	75	75	Low
F_2-Low stability	975	450	75	37.5	75	0	High

2.4. Measurement of emulsion stability

During the chopping process, emulsion samples (~100 g) were obtained at each control time (at time intervals of 1 min up to $t = 8$ min and then at time intervals of 2 min up to $t = 16$ min). Two different emulsion quality parameters (we will use the term quality metrics to describe technological parameters related to meat emulsion quality) such as C_{loss} and G_s were measured on each sample. The samples corresponding to each sampling time were divided into two 50 g emulsion aliquots and stuffed into plastic screw tap test tubes. These aliquots were heat treated in a scalding bath (Mainca S.L., Spain) at 75 °C for 30 min, which ensured an internal temperature in the samples of ~68–70 °C. After thermal treatment, each of two tubes were emptied on a sieve and drained to register the exudation value. The cooked samples were quickly placed into a cooler and stored overnight at 4 °C. The following day, G_s of the gels were determined. G_s was measured using a Bertuzzi Penetrometer (FP Texter, Mod. FT011, IVTPA, Italy). The penetrometer consisted of a manometer and an 11.2 mm cylindrical stainless steel probe. The probe was manually pressed against the sample surface and the minimum pressure required to penetrate the gel structure was registered on the manometer. G_s measurements were performed in duplicate. C_{loss} was calculated in duplicate from the amount of exudates (e.g., jelly and fat) separated from the emulsion during the thermal treatment and the initial weight of the sample before cooking as follows:

$$C_{loss}\ (\%) = \frac{\text{liquid losses during cooking(g)}}{\text{sample before cooking(g)}} \times 100.$$

2.5. Statistical analysis

The data obtained were processed and analyzed using the Statistical Analysis System (SAS, 2002). Pearson correlation coefficients, r, were determined by the correlation (CORR) procedure. The analysis of variance (ANOVA) was performed using the general linear model (GLM) procedure. The least squares means (LSM) and significance of treatments were calculated using type IV sum of squares. LSM were considered to be statistically different when $P < 0.05$. Different regression models for predicting C_{loss} during the gelation process, including independent variables and optical parameters generated from the colorimeter, were tested using the (maximum R^2) procedure of SAS to obtain the best one-, two-, three- and four-parameter

models for prediction of C_{loss}. The evolution of C_{loss} was shown using standard column charts, where the general tendency of the experimental data have been presented using tendency trends, obtained by polynomial fit of the experimental data against chopping time.

3. Results and discussion

3.1. Effect of composition and chopping time on emulsion color, cooking losses and gel strength

Fig. 2 shows the column chart corresponding to C_{loss} at different chopping times (C_t) and the corresponding changes in L^*. The tendency trends associated with C_{loss} (dashed lines) at different chopping times showed that C_t smaller than 2 min resulted in a slightly unstable batter. That agreed with the results of Allais et al. (2004) who observed a reduced adhesiveness of the gel at short C_t. Emulsion stability was at a maximum (e.g., minimum C_{loss}) with chopping time between 2 and 8 min. Further chopping resulted in an unstable emulsion. A very distinct breakdown point was observed after 8 min of chopping, and was accompanied with a significant ($P < 0.001$) increase of liquid exudation. These results agreed with those obtained by other authors (Allais et al., 2004; Barbut, 1998; Girard, 1981) confirming that, under the experimental conditions used, the breakdown point of the emulsion was reached after ~8–10 min of chopping. Fig. 2 also shows that for chopping time greater than 12 min, C_{loss} values were significantly higher ($P < 0.001$) for emulsion F_2 (low emulsion stability) as compared to emulsion F_1 (high emulsion stability). These results agree with those obtained by Serdaroglu (2006) who found the lowest cooking yield in beef patties manufactured without starch and 20% fat as compared to batters having 4% starch and 5% fat. However, insignificant C_{loss} differences were observed for emulsions presenting different breakdown tendency (F_1, F_2) at chopping times between 2 and 8 min. These results suggest that, at short chopping times, optimum extraction of soluble proteins and fat/protein interactions improved water and fat holding capacity of the heat treated emulsion irrespective of the absence/presence of starch.

Lightness (L^*) and redness (a^*) was significantly influenced by the combination of emulsion formula and chopping time. It was observed that meat emulsion lightness, L^*, increased in both emulsions (F_1 and F_2) during the first 3 min, as the fat particle decreased in size and bound more and more of the exposed protein surface. Then, L^* value remained constant at a maximum value at C_t between 3 and 8 min, showing minimum C_{loss} values. Finally, after 8 min of chopping (Fig. 2, arrow), L^* value decreased showing an increasing tendency for liquid exudation during thermally induced gelation. This could potentially indicate the chopping end point. The decreasing trends observed for L^* value after 8–10 min of chopping were not modified by the emulsion type used, which suggested that emulsion lightness measured during chopping could provide useful information for predicting C_{loss} observed during cooking. The observed changes in the color of the emulsion during the chopping process was attributed to a complex combination of physical–chemical changes, probably associated with fat particle size variations, presence of air bubbles and/or protein–fat interactions. According to Palombo, Van Room, Prins, Koolmes, and Krol (1994) the increase of lightness of batters during chopping could be originated by the light scattered from the surface of the product, which is caused by decrease in fat particle size or increase of air bubbles entrapped in the batter matrix. This increase of lightness could also be induced by fat–protein interactions occurring during the chopping process (Girard, Salé, & Simantos, 1981). The redness (a^*) of batters showed a significant decrease ($P < 0.001$) during chopping process in both emulsion formulas which could be explained by the formation of small fat particles and the oxidation of

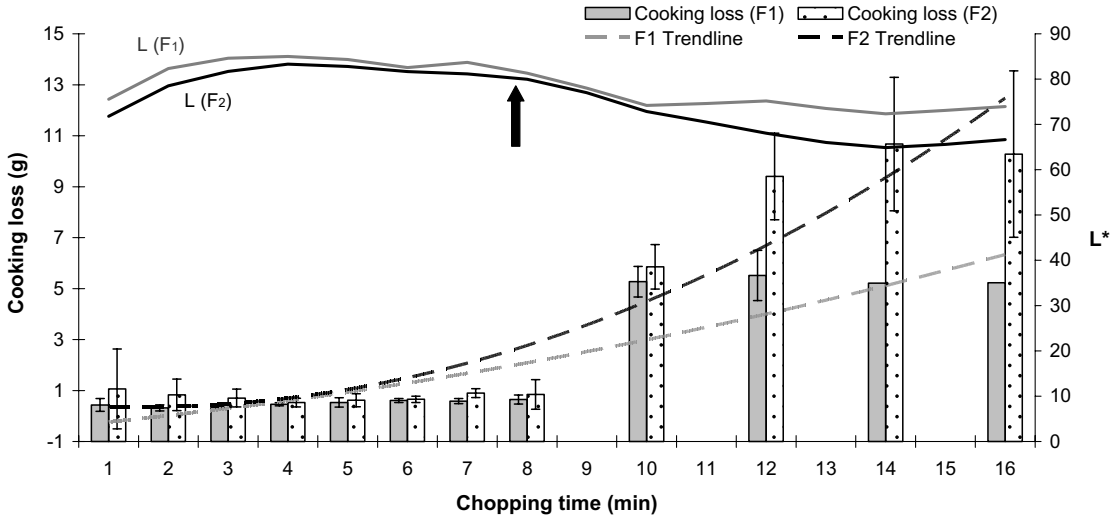

Fig. 2. Evolution of cooking loss and lightness, L^*, at different chopping times as a function of the raw material composition. The arrow identifies the beginning of a "steady" decrease in L^*, which could indicate the chopping end point.

Table 2
Pearson correlation coefficients between dependent and independent variables during the meat emulsification process

	C_t	C_{loss}	G_s	T	L^*	a^*
C_{loss}	0.905^{***}	–	–	–	–	–
G_s	-0.806^{**}	-0.914^{***}	–	–	–	–
T	0.963^{***}	0.799^{**}	-0.742^{**}	–	–	–
L^*	-0.761^{**}	-0.904^{***}	0.818^{**}	-0.638^{*}	–	–
a^*	-0.766^{**}	-0.474^{ns}	0.451^{ns}	-0.873^{***}	0.196^{ns}	–
b^*	-0.925^{***}	-0.851^{***}	0.851^{***}	-0.884^{***}	0.671^{*}	0.748^{**}

$N = 96$. (12 sampling points × 2 emulsion types × 2 reps × 2 duplicates of each measurement). C_{loss}, cooking loss; G_s, gel strength; C_t, chopping time; T, temperature; L^*, lightness; a^* and b^*, chromatic coordinates. Significance; ns $P > 0.05$, $^{*}P \leqslant 0.05$, $^{**}P \leqslant 0.01$, $^{***}P \leqslant 0.001$.

ferrous myoglobin to ferric metmyoglobin (Girard & Denoyer, 1982) or by the globin denaturation (Carlez, Veciana-Nogues, & Cheftel, 1995).

Table 2 shows the Pearson correlation coefficients between the main dependent and independent variables studied. As it can be observed, increasing chopping time significantly ($P < 0.01$) increased temperature ($r = 0.96$) and C_{loss} ($r = 0.91$) and decreased gel strength ($r = -0.81$), and color coordinates L^*($r = -0.76$), a^* ($r = -0.77$) and b^*($r = -0.93$). In agreement with our results, a significant increase of C_{loss} has been observed after 7, 10 and 11 min of chopping by Allais et al. (2004), Barbut (1998), and Girard (1981), respectively, depending of the experimental factors and chopping conditions used. According to Ockerman and Wu (1990), the C_{loss} increase was significantly correlated with an increased emulsion temperature.

As expected, a negative ($r = -0.92$) and significant ($P < 0.001$) correlation between C_{loss} and G_s was found, suggesting that over-chopping might result in softer gels as a result of increased C_{loss}. A negative correlation between C_t and G_s was reported by Barbut (1998), which demonstrates the relationship between separation of liquids and the reduction of product quality. After 8–10 min of chopping, no significant differences were found in gel strength for any of the emulsion formulas. However, Allais et al. (2004) observed that hardness and adhesiveness increased significantly with chopping time. Indeed, meat emulsion temperature significantly ($P < 0.001$) increased ($r = 0.97$) during chopping time as a result of the friction between the emulsion mass and the blades of the cutter. A higher temperature also resulted in larger C_{loss} ($r = 0.80$; $P < 0.01$) and softer gels ($r = -0.74$; $P < 0.01$), which according to Hedrick, Aberle, Forrest, Judge, and Merkel (1994) might be associated to lower meat emulsion quality.

3.2. Cooking loss prediction equations in meat emulsions

The best single-, two-, three- and four-variable models for predicting C_{loss} were selected using the SAS Maximum R^2 procedure. The variables taken into consideration in the selection procedure were the color coordinates L^*, a^* and b^*, temperature (T) and its square (T^2), and the independent variables, chopping time (C_t), and emulsion tendency to breakdown (T_b) represented by the emulsion types F_1 and F_2, where F_1 and F_2 emulsions had low and high tendencies to breakdown, respectively. Replication was included in the model as complementary independent variable to account for possible differences between individual manufactures of the same formula (i.e., replicates of the same treatment). As shown in Table 3, the best single variable model (model I) contained the independent variable C_t and an intercept. This model explained 42% of the variability observed in C_{loss}. Model II showed that the second best predictive parameter of C_{loss} was T_b. The inclusion of T_b in Model I increased the coefficient of determination (R^2), from 0.42 to 0.57. The next best predictors of C_{loss} were the optical variables L^* and the chromatic coordinate, a^*. Inclusion of L^* in Model II increased R^2 from 0.57 to 0.65 while inclusion of a^* on Model III only increased the R^2 value slightly, from 0.65 to 0.69. According to these results, color parameters, a^* and L^*, show potential for on-line prediction of C_{loss}. A practical C_{loss} prediction model for industrial application would require at least two prediction terms, the duration of chopping, C_t, and the emulsion lightness, L^*. However, it should be noted that the proposed models I–IV only explained 42–69% of the observed C_{loss} variability, suggesting that important parameters affecting C_{loss} were not accounted for by the models. A few studies have dealt with the use of on-line instrumental devices to minimize C_{loss} during chopping and/or optimize the texture of the cooked product. Barbut (1998) detect a similar correlation between L^* and C_{loss} and proposed the use of a fiber optic probe as a quality control tool to monitor and predict C_{loss} in meat emulsions. Koolmes, Winjgaards, Tersteeg, and Van Logtestijn (1993) proposed conductimetry measurements to determine the stability of meat emulsion while Allais et al. (2004) successfully predicted the final texture of cooked meat emulsions using front-face fluorescence spectroscopy.

Table 3
Models for the prediction of cooking losses in meat emulsions

Model		β_0	β_1	β_2	β_3	β_4	R^2
I^{***}	$C_{loss} = \beta_0 + \beta_1 C_t$	-1.22^{*}	0.47^{***}	–	–	–	0.42
II^{***}	$C_{loss} = \beta_0 + \beta_1 C_t + \beta_2 T_b$	0.09^{ns}	0.47^{***}	-2.62^{***}	–	–	0.57
III^{***}	$C_{loss} = \beta_0 + \beta_1 C_t + \beta_2 T_b + \beta_3 L^*$	7.49^{***}	0.40^{***}	-3.43^{***}	-0.09^{***}	–	0.65
IV^{***}	$C_{loss} = \beta_0 + \beta_1 C_t + \beta_2 T_b + \beta_3 L^* + \beta_3 a^*$	5.71^{***}	0.45^{***}	-2.45^{***}	-0.15^{***}	0.39^{**}	0.69

$N = 96$. C_{loss}, cooking loss; C_t, chopping time; T_b, emulsion tendency to breakdown; L^*, lightness; a^*, chromatic coordinate a; β_0, β_1, β_2, β_3, β_4, regression coefficients; R^2, determination coefficient. Significance; ns $P > 0.05$, $^{*}P \leqslant 0.05$, $^{**}P \leqslant 0.01$, $^{***}P \leqslant 0.001$.

4. Conclusions

Increasing chopping time significantly increased C_{loss} and decreased G_s and color indexes L^* and b^*. A decrease of the light reflection parameter L^* during chopping, after a steady maximum L^* value, showed potential as an on-line indicator of the optimum chopping end point. Reflection photometry shows promise as an on-line tool to select the optimum chopping endpoint, and predict C_{loss} during manufacture of finely chopped meat products, but further research efforts are needed to improve accuracy of predictions. These results encourage the development of an on-line optical sensor technology for determining emulsion stability during meat emulsion manufacturing.

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