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Application of light extinction to determine stability of beef emulsions

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ABSTRACT

One of the major concerns in the meat processing industry is the loss of emulsion stability resulting in cooking losses. An optical sensor technology to control the emulsification process would minimize this problem. The normalized light intensity (I_N) as a function of fat/lean ratio (R_{FL}; 0.075, 0.25, 0.33) and chopping time (CT; 2, 5, 8 min) were measured at three radial distances (2, 2.5, 3 mm) from the light source to calculate the optical density (OD) and the loss of intensity (I_{Loss}), using a fiber optic spectrometer. ANOVA results were highly significant for I_N, I_{Loss}. Normalized intensity decreased with increased chopping time as a result of emulsion homogenization, and with increased distance. Chopping time had a positive correlation with fat losses during cooking, which in turn had a negative correlation with I_N and I_{Loss}. These results suggest that light extinction spectroscopy could provide information about emulsion stability.

1. Introduction

Finely comminuted meat product manufacturers need to enhance production efficiency to reduce energy consumption, production time and production cost while increasing yield and ensuring the quality, homogeneity and safety of products. Many new food safety concepts have been developed during the last few years: Total quality management (TQM), ISO 9000 Certification, or Traceability that require intensive and improved control authentication, as well as effective monitoring systems. According to Holm (2003), the great challenge is indeed to focus on the real-time and on-line sensors to control the automated process needed to obtain final product quality. Consequently, the needs for process control are essential in all stages of meat production to avoid emulsion defects. Thus the investigation of the colloidal interactions which lead to stability of food emulsion systems is critical (Corredig and Alexander, 2007). A better understanding of the initial stages of colloidal interactions would lead to optimization of meat emulsion formulation, process control, and final product quality. Meat emulsification is of significant economic importance to the meat processing industry, especially when inevitable changes in the processing system occur resulting in meat emulsion instability. Table 1 shows the estimated cost of cooking losses to the US meat industry, based on a hot dogs production of ~1 billion kg per year in 2007 and assuming an average cooking loss (% of weight) of 15.4%, 2.64%, and 21.2% as a result of under-, optimum, and over-chopping, respectively (Brown and Toledo, 1975; Barbut, 1998; Álvarez et al., 2006). Potential economic losses range between 0.20 and 1.65 billion dollars per year depending on chopping conditions (NHDSC, 2008). This large economic impact suggests that meat emulsion manufacturing would benefit from the development of suitable sensors for monitoring the emulsification process, reducing the economic impact of emulsion breakdown during manufacturing. A brief summary of methods that have been proposed over the years to evaluate different parameters for process control in meat and meat products can be consulted in Álvarez et al. (2009). Currently, the selection of an optimum duration of the chopping process during emulsification of finely comminuted meat products lacks an effective on-line sensor technology. A novel

Abbreviation: L^*, lightness; a^*, redness; b^*, yellowness; T, temperature; C_L, cooking loss; C_{LF}, fat loss; R_{FL}, fat/lean ratio; CT, chopping time; D, distance between optical fibers; IT, integration time; IT_1, integration time at $D = 2$ mm; IT_2, integration time at $D = 2.5$ mm; IT_3, integration time at $D = 3$ mm; I_N, normalized light intensity; I_{N1}, normalized light intensity at D = 2 mm; I_{N2}, normalized light intensity at D = 2.5 mm; I_{N3}, normalized light intensity at D = 3 mm; OD, optical density; OD_{1-2}, optical density between distances 2 and 2.5 mm; OD_{1-3}, optical density between distances 2 and 3 mm; I_{Loss}, loss of intensity; $I_{Loss1-2}$, loss of intensity between distances 2 and 2.5 mm; $I_{Loss1-3}$, loss of intensity between distances 2 and 3 mm.

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Table 1
Economic impact of meat emulsion stability on finely comminuted meat products according to the cooking losses originated by different chopping durations.[a]

	Under chopping <2 min	Optimum chopping (adequate emulsion stability) 2–8 min	Over-chopping >8–10 min
Cooking loss rate, %	15.4	2.64	21.21
Annual product loss, million kg	154	26.4	212
Economic loss, billion $	1.20	0.20	1.65

[a] Cooking losses calculated on the basis of an annual hot dog consumption of one billion kg (NHDSC, 2008).

light backscatter fiber optic sensor technology capable of measuring light attenuation within the meat emulsion in order to monitor the maximum stability degree (i.e. minimum cooking losses) during beef meat emulsification would be of great interest to the industry. Emulsion control will also require correlating some key quality metrics (e.g., cooking losses, hardness) with optically generated parameters to predict an optimal chopping process endpoint.

The goal of this study was to investigate light extinction measurements collected from beef emulsions having different fat proportions at various chopping durations and at several optical radial distances to evaluate changes in comminuted meats that may be correlated with those technological parameters associated with emulsion stability (e.g., total cooking losses, water separation, and fat separation). The study of meat emulsion optical properties is essential for the development of an on-line sensor technology capable of monitoring stability during the emulsification process, avoiding the incidence of meat emulsion defects. The use of a real-time sensor in the meat industry to control the chopping process would have a large impact on meat emulsion manufacturing worldwide in terms of product quality and production efficiency.

2. Materials and methods

Data analyzed in this study correspond to the data set presented by Álvarez et al. (2009), where details of the material and methods were explained. Only a brief description of aspects of special relevance is provided here. A randomized block design (blocking factor; chopping length, CT: 2, 5 and 8 min) with three replicates was performed to gather basic information about the light extinction properties of beef emulsions. A batch of meat was assigned to each block. Tests within each block were performed at different levels of fat/lean ratio (R_{FL}: 0.075, 0.25 and 0.33) and distance (D; 2, 2.5 and 3 mm) between the light emitting and detecting optical fibers. Since block and batch effects were not independent, the three different meat batches were analyzed to disregard a potential confounding effect between meat batch and the experimental blocks. The least square means for R_{FL} corresponding to the three different meat batches were not significantly ($P < 0.05$) different, which discard a batch-block confounding effect. Pre-frozen ground beef samples and ingredients were comminuted in a bowl chopper at 1,750 rpm. Temperature, pH, CIE $L^*a^*b^*$ values and the chemical composition (fat and moisture levels) of the fresh emulsions were measured. Two emulsion aliquots of 30 g each were heat treated in a scalding bath at 70 °C for 30 min to measure the total cooking loss (C_L) by mass balance. Fat loss (C_{LF}) of the samples was also estimated. Light backscatter profiles were obtained from the fresh emulsions as proposed by Álvarez et al. (2009) using a dedicated laboratory optical sensor prototype, which was designed to set the radial distance between the optical emitting and detecting fibers by means of a micrometer (Fig. 1). Before measurement, the terminating ends of the fibers were aligned vertically to the same elevation and adjusted horizontally to minimal separation between fibers (2 mm centerline distance). The fiber tips were immersed into the emulsion samples (~25 mm of depth) up to a final depth of ~12.7 mm from the surface. Scans were taken beginning with the fibers touching; a radial distance of 2 mm. This procedure was repeated in sequences of 0.5 mm radial increments until collect two additional scans at 2.5 and 3 mm of radial distance. As it can be observed, light from a tungsten halogen bulb (LS-1, Ocean Optics, Inc., spectral range 300–1100 nm) was transmitted to the probe tip using a fiber optic cable of 0.6 mm of diameter. Light reflected from the meat emulsion matrix particles was transmitted through the receiving fiber to a high-resolution fiber optic spectrometer (HR4000, Ocean Optics, Inc., 300–1100 nm).

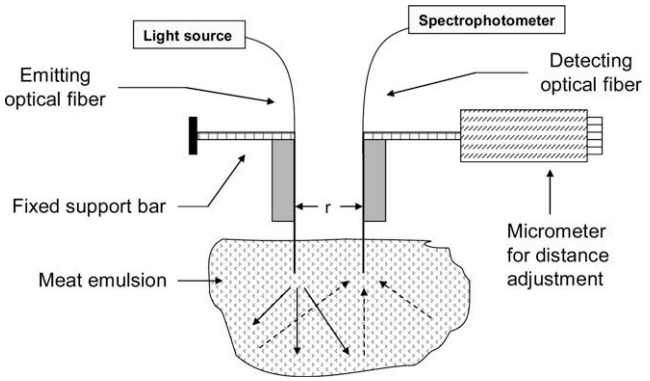
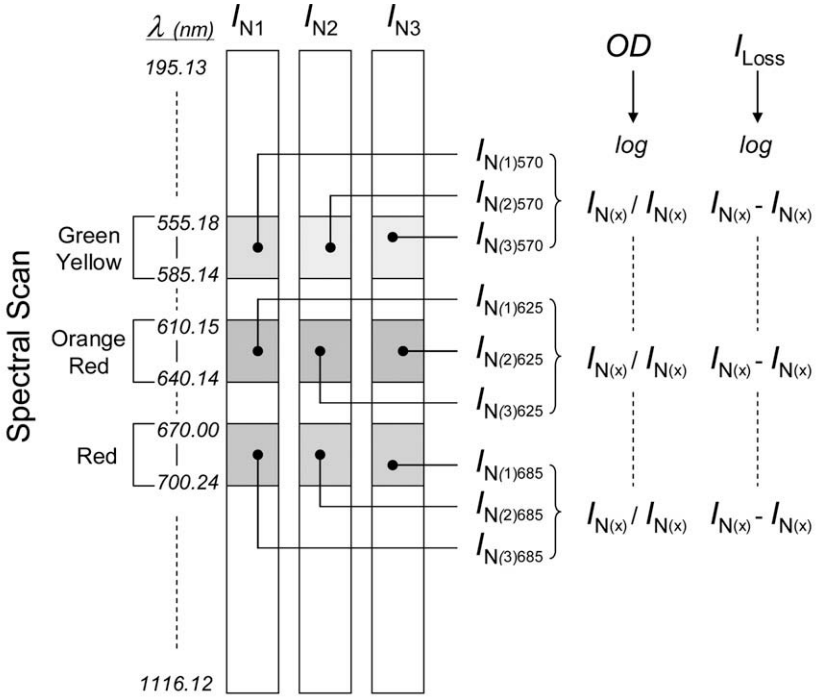


Fig. 1. Schematic representation of the optical configuration used to measure light backscatter in meat emulsions at different radial distances (r) from the light source (r = 2, 2.5 or 3 mm), using a fiber optic of 0.6 mm diameter. The fiber tips were immersed 12.7 mm into the sample, which had a total depth of 25 mm.

2.1. Optical parameters analyzed

The light scattering spectral scans, $I(\lambda)$, corresponding to each chopping time, R_{FL} and distance between fibers were automatically processed by subtracting the respective dark spectral scans and dividing by the integration time (IT; range 19–60 s) to give the normalized spectral light scattering scans, $I_N(\lambda)$ (bits s^{-1}). Each spectral scan was reduced to three intensity averages by dividing them into three wavebands, averaging the normalized intensity for the wavelengths constituting each waveband, and assigning the average values to the corresponding waveband center point. The selected wavebands were *green-yellow region* (555–585 nm), *orange-red region* (610–640 nm) and *red region* (670–700 nm) and the corresponding center points were 570, 625 and 685 nm, respectively. For each given R_{FL} and CT treatment combination, the calculated normalized intensity averages ($I_{N(x)}$, were x = radial distance from the light source) corresponding to different distances were used to calculate the optical density (OD; $\log I_{N(x)}/I_{N(x)}$) and the loss of intensity (I_{Loss}; $\log (I_{N(x)} - I_{N(x)})$). A brief description of these optical parameters derived from the light backscatter profile is provided in Fig. 2. Note that OD is not used here in place of absorbance as both light absorbance and scatter contribute to the extinction of light inside the emulsion samples. Fig. 3 shows typical OD and I_{Loss} profiles obtained at all wavelengths from 550



*OD is not used here in place of absorbance; note that both light absorbance and scatter contribute to the extinction of light inside the emulsion samples.

Fig. 2. Schematic representation of the spectral scan regions analyzed (*green-yellow, orange-red*, and *red*) and the normalized intensities (I_N, bits s^{-1}) obtained at different distances (x = 2, 2.5 or 3 mm) between fibers used to calculate the optical density (OD^*) and the loss of light intensity (I_{Loss}). I_{N1}, I_{N2} and I_{N3} are the normalized intensities at distances 2, 2.5 and 3 mm, respectively. OD_{1-2} and $I_{Loss1-2}$ are optical density and loss of intensity between distances 2 and 2.5 mm and OD_{1-3} and $I_{Loss1-3}$ between distances 2 and 3 mm.

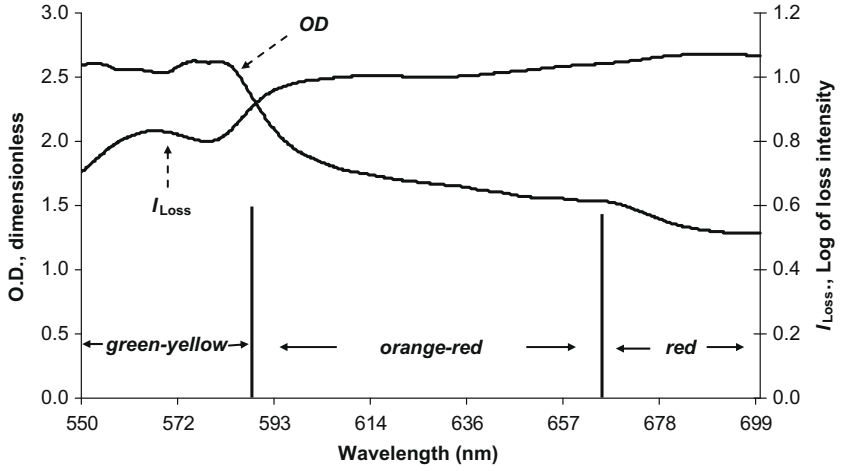


Fig. 3. Representation of the optical density (OD_{1-3}) and loss of intensity ($I_{Loss1-3}$) profiles versus wavelength (550–700 nm), in a representative beef emulsion sample (0.25 R_{FL}, 2 min CT).

to 700 nm (*green-yellow, orange-red and red regions*) in a representative beef emulsion sample.

2.2. Statistical analysis

The data were analyzed using the Statistical Analysis System (SAS®, 2002). Pearson correlation coefficients, *r*, were determined by the correlation (CORR) procedure of SAS. The analysis of variance (ANOVA) was performed using the general linear model (GLM) procedure of SAS. 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 $P < 0.05$.

3. Results and discussion

Dependent variables tested for monitoring the degree of meat emulsification in fresh ground beef were classified as optical (*IT*, I_N, OD and I_{Loss}), color (L^*, a^* and b^*), and meat emulsion metric (pH and cooking loss) parameters. An ANOVA was independently conducted for each one of the spectral scan regions studied

Table 2
Analysis of variance and *F* statistics for dependent variables for the *orange-red spectral scan region* (625 nm).[a]

	Model		Variation source			
			CT (DF = 2)	R_{FL} (DF = 2)	*T* (DF = 1)	CT × R_{FL} (DF = 4)
	R^2	*F*	*F*	*F*	*F*	*F*
IT_1	0.96	45.5***	37.8***	4.13*	ns	3.92*
IT_2	0.94	31.7***	24.5***	ns	ns	4.52*
IT_3	0.95	34.4***	46.6***	ns	ns	ns
I_{N1}	0.95	33.8***	20.9***	4.07*	ns	9.34***
I_{N2}	0.94	28.7***	17.1***	ns	4.54*	5.64**
I_{N3}	0.92	21.1***	11.3***	ns	ns	5.44**
OD_{1-2}	0.51	ns	ns	3.64*	ns	ns
OD_{1-3}	0.44	ns	ns	ns	ns	ns
$I_{Loss1-2}$	0.65	3.55*	ns	ns	ns	ns
$I_{Loss1-3}$	0.94	31.4***	16.7***	ns	ns	9.06***
pH	0.94	32.0***	104***	6.42**	ns	ns
L^*	0.98	80.7***	12.3***	84.9***	31.2***	10.4***
a^*	0.95	35.8***	83.8***	19.2***	ns	7.92***
b^*	0.98	93.4***	51.9***	114***	17.6***	13.2***
C_L	0.88	13.7***	10.7***	33.5***	ns	3.53*
C_{LF}	0.89	15.7***	ns	28.8***	5.74*	4.29*

ns Not significant. CT, chopping time; R_{FL}, fat-lean ratio; *T*, temperature, *CT* × R_{FL}, chopping time × fat-lean ratio. For the definitions of dependent variables, see the material and methods section. Range values of IT_1, IT_2 and IT_3 were 19–39 s, 28–51 s, and 36–60 s, respectively.
[a] *N* = 27; *F*, ANOVA *F* statistic; DF, degree of freedom; DF error = 17; DF model = 26. R^2, determination coefficient.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

(*green-yellow, orange-red and red regions*) to determine the main sources of variation in the dependent variables. In Table 2, only ANOVA and *F* statistics corresponding to the studied parameters for the yellow-orange region were shown to avoid unnecessary redundancy, because the response of parameters was similar in the three spectral scans. Replicate (Rep), fat/lean ratio (R_{FL}), chopping time (CT) and temperature (*T*) were selected as main effects in the preliminary ANOVA model. The main interaction "CT × R_{FL}" was also included. Replication effect was not significant and was removed from the model. The ANOVA model was highly significant for *IT*, I_N and I_{Loss} but not significant for OD. Chopping time was found to have a statistically significant ($P < 0.001$) effect on all optical dependent variables, except for OD and $I_{Loss1-2}$. The interaction "CT × R_{FL}" had a statistically significant effect on IT_1, IT_2, I_N, and $I_{Loss1-3}$. The main effect R_{FL} was significant ($P < 0.05$) for optical parameters IT_1, I_{N1}, OD_{1-2}, while the *T* was only significant ($P < 0.05$) for I_{N2}. Regarding color and metric measurements, the ANOVA model was highly significant ($P < 0.001$) for all the parameters. CT was found to have no significant effect on C_{LF}, while the effect of the meat emulsion temperature was not significant for pH, a^* and C_L. The interaction "CT × R_{FL}" had no significant effect on pH.

3.1. Emulsion quality metrics and light backscatter response

According to Table 3, Pearson correlations between the emulsion quality metrics and optical measurements were strong in all cases except for the optical density. The physical–chemical changes occurred during the emulsification process, for the most part related with changes in the emulsion temperature and pH, were also correlated with many of the optical measurements, as expected. The fat losses observed during cooking were strongly correlated with the optical parameters derived from the light backscatter spectral scans (I_N and I_{Loss}). These correlations suggest that changes in C_{LF}, could be predicted by optical changes detected during the emulsification process, preventing a potential loss of water and fat during cooking. However, the temperature of the emulsion plays an important role in this correlation as both optical parameters (I_N and I_{Loss}) decrease as *T* increases. Light backscatter measurements were also significantly correlated with all the color parameters (Table 3). A negative correlation was observed between light backscatter intensity and both L^* and chromatic coordinate values. Previous studies (Barbut, 1998) have shown that luminosity is strongly correlated with changes of the emulsion stability related with cooking losses. Our results suggest that light backscatter

Table 3
Pearson correlations between dependent variables obtained by light backscatter at 625.15 nm (*orange-red* spectral scan), color and metrics measurements.[a]

	CT	pH	*T*	L^*	a^*	b^*	C_{LF}
I_{N1}	−0.88***	−0.59**	−0.78***	−0.73***	−0.51**	−0.60***	−0.62***
I_{N2}	−0.90***	−0.62***	−0.79***	−0.78***	−0.53**	−0.69***	−0.57**
I_{N3}	−0.88***	−0.46*	−0.80***	−0.77***	−0.38*	−0.61***	−0.63***
OD_{1-2}	ns	ns	ns	ns	ns	ns	ns
OD_{1-3}	ns	ns	ns	ns	ns	ns	ns
$I_{Loss1-2}$	−0.61***	ns	−0.56**	−0.51**	ns	ns	−0.52**
$I_{Loss1-3}$	−0.89***	−0.52**	−0.78***	−0.76***	−0.44*	−0.61***	−0.65***

ns Not significant. For the definition of dependent variables, see the material and methods section. The correlations between optical measurements and both R_{FL} and C_L variables were removed from the table as consequence of the low correlation detected.
[a] *N* = 27.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 4
Influence of main effects, fat/lean ratio and chopping time, on light backscatter parameters derived from the *orange-red* spectral scan region (625 nm).[a]

	Fat/lean ratio (dimensionless)			Chopping time (min)		
	0.075	0.25	0.33	2	5	8
I_{N1}	220ab	241[a]	208[b]	308[a]	204[b]	157[c]
I_{N2}	117[a]	109[a]	119[a]	159[a]	102[b]	84.0[b]
I_{N3}	60.6[a]	57.2[a]	53.2[a]	76.0[a]	56.1[b]	38.8[c]
OD_{1-2}	0.27[ab]	0.33[a]	0.26[b]	0.29[a]	0.30[a]	0.29[a]
OD_{1-3}	0.56[a]	0.62[b]	0.59[ab]	0.61[a]	0.57[a]	0.61[a]
$I_{Loss1-2}$	1.99[ab]	2.06[a]	1.91[b]	2.09[a]	2.00[a]	1.86[a]
$I_{Loss1-3}$	2.18[ab]	2.21[a]	2.15[b]	2.34[a]	2.16[b]	2.04[c]

[a] $N = 27$. LSM with same letters were not significantly different ($P < 0.05$); number of replications = 3; For the definition of dependent variables, see Section 2.

intensity, highly correlated with L^* ($P < 0.001$), could have potential as an indicator of meat emulsion stability during cooking. This finding shows the feasibility of an optical sensor technology for predicting the optimum chopping end-point to control the meat emulsion stability.

3.2. The effect of chopping time on optical parameters

The effect of CT on light backscatter parameters derived from the orange-red spectral scan region (625 nm) is shown in Table 4. A significant ($P < 0.001$) decrease of I_{N1}, I_{N3} and $I_{Loss1-3}$ was found when CT increased from 2 to 8 min. Optical densities and the absolute loss of intensity at radial distance 2.5 mm, $I_{Loss1-2}$, did not change significantly as a function of CT. However, as it can be observed in Table 4, $I_{Loss1-3}$ decreased significantly ($P < 0.001$) as CT increased. Fig. 4A shows that normalized intensity average values decreased with increasing chopping duration (66–69%) and radial distance (56–59%). The largest reduction of I_N for each CT (2, 5 and 8 min) as radial distance increase from 2 to 3 mm, was observed for CT of 2 min (69.6%) and 8 min (68.6%), while the reduction observed at 5 min was lower (66.5%). This I_N behavior might be associated with the structural changes observed in the emulsion during the chopping process where the matrix changes from a high heterogeneity at 2 min CT to another with high homogeneity at 8 min CT. It was also observed (Fig. 4A) that intensity reductions between 2 and 5 min of CT (38.3%), at the three radial distances, were higher than those reductions of intensity between 5 and

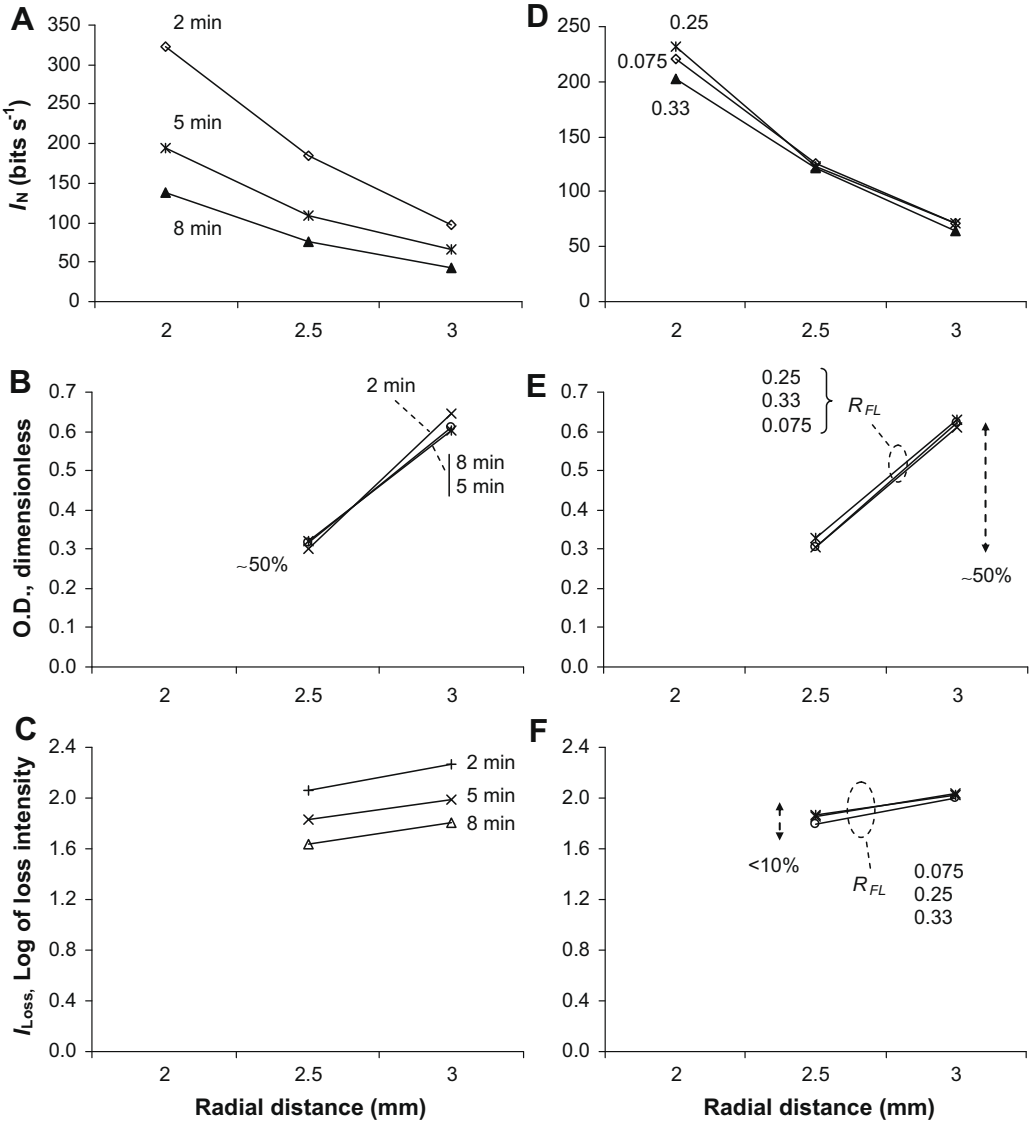


Fig. 4. Average values (550–700 nm) of normalized intensity (I_N; A, D), optical density (OD; B, E) and loss of intensity (I_{Loss}; C, F) measured at different radial distances (mm) and as a function of chopping time (CT; A, B, C) and fat/lean ratio (R_{FL}; D, E, F).

8 min of CT (31.3%). This suggests that during earlier stages of chopping the particle size shows a great variability as a result of the heterogeneous nature of the meat matrix, but according CT increases the particle size reaches a constant point of homogeneity in which the intensity changes are every time lower. On the other hand, the largest reduction of I_N for each optical distance (2, 2.5 and 3 mm) as CT increase from 2 to 8 min (Fig. 4A) was observed at 2.5 mm (58.9%, from 185 to 76 bits s^{-1}) and 2 mm (57.4%, from 322 to 137 bits s^{-1}) of radial distance, while the reduction at 3 mm of distance was slightly lower (56.1%, from 98 to 43 bits s^{-1}). These results suggest the dependency of the loss of I_N measured during meat emulsification with the optical radial distances. A similar optical intensity behavior was obtained by Crofcheck et al. (2000) in skim milk samples measured at different radial distances from the light source. Fig. 4 also shows a linear increase of the optical density (Fig. 4B) and loss of intensity (Fig. 4C) as radial distance increases from 2 to 3 mm. This increase was higher for OD (~50%) as compared to I_{Loss} (~10%). However, while no significant differences ($P > 0.05$) were found in the optical densities at different CT, $I_{Loss1-3}$ significantly decreased ($P < 0.001$) with increases of CT (Table 4). This behavior can also be observed in the Fig. 5 where the average OD (Fig. 5A) and I_{Loss} (Fig. 5B) profiles are represented between 550 nm and 700 nm. Minimal differences between all the OD profiles at 2–8 min of CT were observed in the *orange-red* and *red* regions (Fig. 5A), while the OD profiles had a clear tendency to decrease in the *green-yellow* region as CT increase. On the contrary, clear differences in the entire spectral scan studied (550–700 nm) can be observed for I_{Loss} profiles as a function of CT (Fig. 5B). Also observed is a typical local maximum (~560 nm) and minimum (~575 nm) in each I_{Loss} profile. Figs. 5A and 5B show that the lowest OD and I_{Loss} values were basically associated with long CT (8 min), especially at wavelengths ranging from 555 to 585 nm in the OD profiles (Fig. 5A). In the *green-yellow region* (555–585 nm) a higher optical signal resolution was also observed when compared with the *orange-red* and *red* regions. In these spectral scans, the values of OD decrease and become noisier and the values of I_{Loss} show a constant behavior without oscillations. This fact was attributed to higher sensitivity of green-yellow light (555–585 nm) to structural changes occurring during the emulsification process. Moreover, as it has been previously described in Fig. 4A, larger reduction of I_N was observed at short radial distances between optical fibers.

3.3. The effect of fat/lean ratio on optical parameters

The effect of R_{FL} on light backscatter parameters studied at 625 nm (*orange-red* region) is showed in Table 4. A significant ($P < 0.05$) decrease of the optical parameters I_{N1}, OD_{1-2}, $I_{Loss1-2}$ and $I_{Loss1-3}$ when R_{FL} increase from 0.25 to 0.33 was detected. Also it was observed that optical density (especially OD_{1-3}) increased significantly ($P < 0.05$) as R_{FL} increased from 0.075 to 0.25, but above this R_{FL} value, the optical density (especially OD_{1-2}) showed a significant decrease as R_{FL} increased until 0.33. The increase of this optical parameter until a specific value of fat in the meat emulsion agrees with the results obtained by Payne and Danao (2004) using a light extinction sensor in milk samples with fat values <50%. The authors observed that a ratio of light intensities, measured at two radial distances from the light source (I_1/I_2), was linearly and positively correlated with the milk fat content. Table 4 also shows that R_{FL} was not significant for the rest of parameters derived from light backscatter (I_{N2} and I_{N3}). As it can be observed in the Fig. 5C, the OD of the emulsions manufactured with R_{FL} 0.25 had a slight tendency to increase in the *orange-red* and *red* regions, while an irregular behavior was observed in the green-yellow region. In the *orange-red* and *red* spectral regions, the OD value for R_{FL} 0.075 clearly decreased as compared with emulsions made with high proportion of fat. Fig. 5D shows that I_{Loss} profiles progressively increase with increasing wavelength. However, in the *green-yellow* region, I_{Loss} was observed to slightly increase as R_{FL} decreased. Two local I_{Loss} maxima and minima were consis-

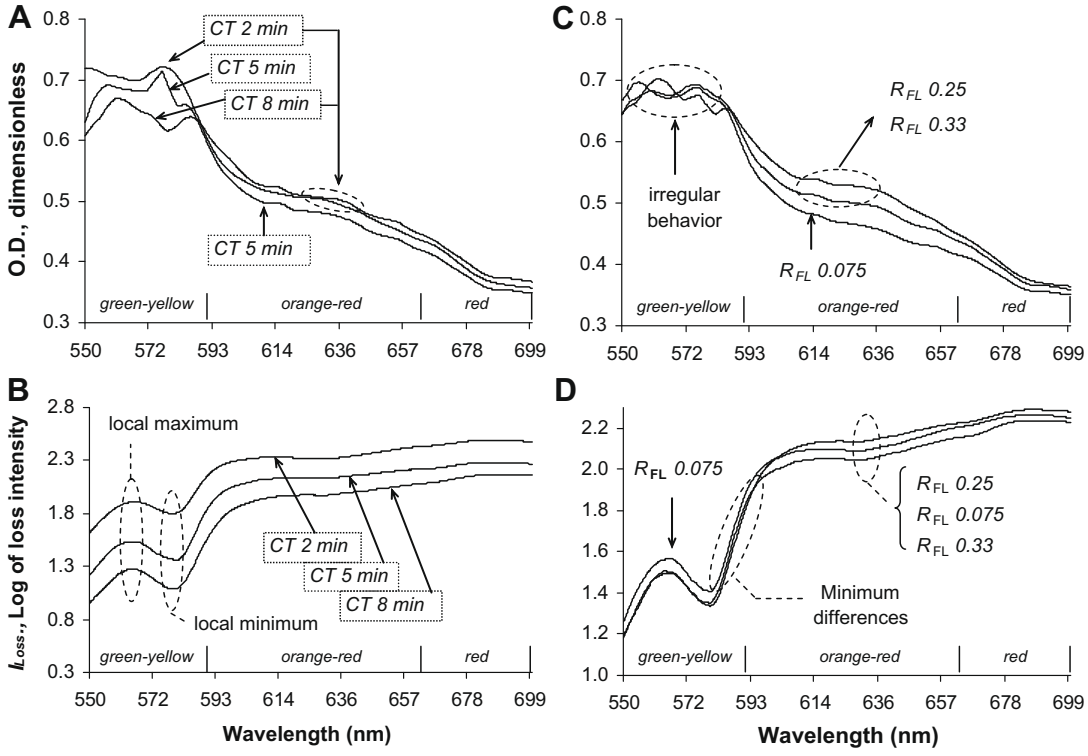


Fig. 5. Average profiles of optical density (OD; A, C) and loss of intensity (I_{Loss}; B, D) as a function of chopping time (CT; A, B) and fat/lean ratio (R_{FL}; C, D).

tently identified at ~560 nm and ~575 nm, respectively, independently of the R_{FL} studied. These local maxima/minima might be related with the absorbance spectra of extracted pigments. According to Swatland (1982), myoglobin has an absorbance peak at ~565 nm, and the oxymioglobin has two peaks (~542 and ~575 nm), one on either side of the myoglobin. The shape of these profiles suggests that increases of R_{FL} up to R_{FL} values of 0.25 are associated with increases of the optical density in wavelengths above 585 nm (Fig. 5C) and the subsequent loss of light intensity (Fig. 5D), although the results were not conclusive for the I_{Loss} profiles. This behavior can be also observed in the Fig. 4E, where the average values of OD increased up to 50% with increasing R_{FL} from 0.075 to 0.25, while the I_{Loss} values (Fig. 4F) showed a slight increase (<10%) as R_{FL} decrease from 0.33 to 0.075, respectively. Thus, although the light intensity values only showed significant ($P < 0.05$) differences at 2 mm of distance (I_{N1}) between the highest fat-lean ratios, 0.25 and 0.33, (Fig. 4D, Table 4), the results obtained from the optical parameters derived from light backscatter profile, especially I_{Loss}, suggest that light extinction spectroscopy could provide information about meat emulsion stability. The ability of I_{Loss} to estimate fat exudates during emulsion manufacturing could also be useful to design of an on-line meat emulsion stability optical sensor for finely chopped meat products.

4. Conclusions

Chopping duration had a significant effect on optical parameters, normalized intensity and loss of intensity. These optical parameters were highly correlated with changes in lightness during beef emulsion manufacturing as well as with cooking fat exudates. The findings strongly suggest the feasibility of these optical parameters as potential predictors of meat emulsification degree and potential fat exudates. The information reported by the normalized intensity and loss of intensity could have potential use in the development of a new on-line optical sensor technology to select the optimum end-point of chopping that would be able to minimize cooking losses and maximize the yield. Successful development of this technology would also provide useful optical information about the meat emulsion matrix and their large structural changes during processing. The results obtained in this study suggest that light extinction measured in meat emulsions effectively chopped before breakpoint is reached (~8 min) at wavelengths of 555–585 nm and radial distance from the light source $\leqslant$2.5 mm could provide useful information about the degree of meat emulsification (i.e., meat emulsion stability).

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