LIGHT BACKSCATTER FIBER OPTIC SENSOR: A NEW TOOL FOR PREDICTING THE STABILITY OF PORK EMULSIONS

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Abstract – The objective of this study was to determine whether light backscatter response from fresh pork meat emulsions is correlated to final product stability indices. For that, a specially designed fiber optic measurement system was used in combination with a miniature fiber optic spectrometer to determine the intensity of light scatter within the wavelength range 300-1100 nm at different radial distances (2, 2.5 and 3 mm) with respect to the light source in fresh pork meat emulsions with two fat levels (15, 30%) and two levels (0, 2.5%) of hydrolyzed potato protein (*HPP*), a natural antioxidant. Textural parameters (hardness, deformability, cohesiveness and breaking force), CIELAB colour coordinates and *TBARS* (1, 2, 3, and 7 days of storage at 4ºC) of cooked emulsions were also measured. Several optically derived parameters were found to be significantly correlated with emulsion stability parameters. The light backscatter was directly correlated with breaking force, colour and TBARS. Based on the strongest correlations developed, an optical configuration is proposed that would compensate for the emulsion heterogeneity, maximizing the existing correlation between the optical signal and the emulsion quality metrics.

Key Words – Frankfurters, Texture, Color, Lipid oxidation

I. INTRODUCTION

According to Barbut [1], fat stabilization during chopping of meat emulsions such as frankfurters is due to the formation of a protein film around the fat particles that allows retaining fat inside the protein matrix. During chopping, certain attractive forces contribute to hold the raw materials together and create a homogeneous matrix structure [2]. Excessive reduction of fat particles size and inadequate soluble protein extraction or fat to protein ratio could lead to reduced emulsification ability and increased fat oxidation tendency.

Therefore, the development of novel techniques for the meat emulsion quality analysis is required by the food industry in order to complement the traditional analysis methods [3]. Specifically, light-scatter measurements have been applied for measuring the degree of meat emulsion stability during hot dog manufacturing [4]. The use of a real-time meat sensor technology having the ability to determine the optimum fat emulsification degree and emulsion stability (e.g., obtaining meat emulsion with the maximum stability and minimum cooking losses) in meat could be a good strategy to improve the current control over the emulsification process. This will not only improve the texture of the cooked meat emulsion but would also prevent cooking losses, which in turn would result in evident final product consistency, quality and economic gain.

The objective of this study was to find a relationship between the light backscatter response in meat emulsions and the degree of chopping of the emulsions, hypothesizing that if the meat emulsion particles do change in size during chopping after heat exposure, this will change the light backscatter of the fresh meat and these measurements are correlated with parameters after cooking, because the degree of coping changes the size of particles and this impact in the stability of final emulsion. This new method, if successfully implemented, will assist meat products in industry in the efficient use of fat/lean/time and selection of choping/temperature and ensure production of high-quality products. These characteristics give it the potential to be developed into an inline measurement technology for evaluating meat's suitability in hot dogs or bolognas manufacture based on the level of fat concentration used.

II. MATERIALS AND METHODS

Experimental design. A completely randomized factorial design with two factors and three replications was used. Two different *HPP* levels (0 –control – and 2.5% *w/w*) were tested within a range of emulsion breakdown and lipid oxidation tendencies that were induced by using two different levels of fat (15 and 30% *w/w*; i.e., fat/lean ratios, R_{FL}, of 0.18 and 0.43, respectively). A total of 12 tests (N = *nab* = 3·2·2) were conducted with this design. A variety of final product quality indices (technological dependent variables) were determined to establish the degree of lipid oxidation (thiobarbituric acid-reactive substances or *TBARS*) and emulsion stability (hardness, cohesiveness, deformability and breaking force) of the cooked meat emulsions.

Meat samples and HPP preparation. Treatment formulations for the frankfurters were adapted from Feng et al. [5] (Table 1). Potato protein concentrate was suspended in aqueous solution to obtain a 15% w/v protein concentration, and the pH was adjusted to 8.0 with 1 N NaOH. Protein was hydrolyzed with alcalase for 1 h at 50ºC, using an enzyme/substrate ratio of 0.01. For further details, refer to Wang *et al*. [6]. Raw material mixtures were chopped using a 9 kg capacity bowl chopper (CM-14, Mainca, St. Louis, MO, USA). Knife and bowl speeds of 3000 and 10 rpm, respectively, were used. The raw emulsion was immediately split into two homogeneous aliquots. The first aliquot was used to measure light backscatter of the raw emulsions. The second aliquot was stuffed into 27 mm diameter frankfurter, weighed and cooked for 90 min in an Alkar smokehouse (450 U, Alkar- RapidPak Inc., Lodi, WI, USA) to an internal temperature of 71ºC. After cooking, the frankfurters were immediately cooled with cold water for 2 min, packed in polystyrene trays, overwrapped with oxygen-permeable film (650 $cm^3\ m^{-2}\ h^{-1}$ at 23ºC), and stored at 4ºC for 7 days to evaluate the inhibitory effect of *HPP* on lipid oxidation.

Table 1 Formulation[1] of frankfurters used for the different experimental treatments.

Formula	Experimental treatments			
	0% *HPP*		2.5% *HPP*	
Fat %	15%	30%	15%	30%
Fat/lean ratio	0.177	0.429	0.177	0.429
Raw mat.(g)				
Fat+Lean	3565	3565	3565	3565
HPP [2]	0	0	667	667
Water	860	860	193	193
Ice	500	500	500	500
Salt[3]	75	75	75	75
Total	5000	5000	5000	5000

[1]Source of original formulation: Feng et al (2003).
[2]The mass of hydrolyzed potato protein (*HPP*) solution used amounts to 2% of frankfurter formulation.
[3]The amount of NaCl used gives a 1.5% Salt content

Color. CIELAB color coordinates, L^*, a^*, and b^*, were measured 1 h after the emulsion was prepared using a hand held tristimulus Chroma Meter (CR-310 Minolta Camera Co., Ltd., Osaka, Japan). Coordinates a^* and b^* were used to calculate both Chroma, C^*_{ab}, and Hue, H^0_{ab}, values as follows:

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}} \qquad H^0_{ab} = \arctan(b^* / a^*)$$

Texture profile analysis (TPA). The influence of *HPP* and fat concentration on textural properties of frankfurters was investigated by uniaxial compression tests using an Instrom Universal Testing Machine (Model 4301; Instrom Corp., Canton, MA, USA) as described by Xiong *et al*. [11]. Cylindrical samples of 1.5 cm length were cut and compressed, using a 100 N load cell at a crosshead speed of 50 mm min^{-1}, to 80% of its original height (strain, $\varepsilon = \Delta L/L_0 = 0.2$, were L_0 is the initial length of the cylinder) in a two cycle compression with 15 s delay between cycles. Hardness (H) of the sample was measured as the force (N) of the first compression peak (F_1). Another set of nine samples was compressed to 20% of its original height ($\varepsilon = 0.8$) to determine the breaking force (FB) (N).

Thibarbituric Acid-Reactive Substances (TBARS). TBARS were measured on days 0, 1, 3 and 7 of storage at 4 ºC, according to the method described by Wang *et al*. [9].

Light backscatter measurement. Light backscatter profiles were obtained from the fresh pork emulsions using a dedicated laboratoryscale optical sensor prototype, which was designed to set the radial distance between the optical emitting and detecting fibers by means of a micrometer. Two small plastic probes were built and configured such that light scatter from the sample could be detected using a High-Resolution Fiber Optic Spectrometer (Model HR4000, Ocean Optics, Inc., Dunedin, FL, USA). The light source utilized was a tungsten halogen (300– 1100 nm) bulb (LS-1, Ocean Optics, Inc.). Fiber optic cables were manufactured using 600 µm diameter fibers (Spectran Specialty Optics, Avon, CN, USA). The terminating (i.e., measuring) ends of the two fibers were built into the plastic probes while the other two ends were connected, using an SMA connector, to the spectrometer and light source, respectively. Before measurement, the terminating ends of the fibers were aligned vertically to the same elevation and adjusted horizontally. The fiber tips were immersed into the emulsion sample up to a final depth of 12.7 mm from the surface of the sample. The temperature of the sample was controlled by means of connecting the sample holder to a water bath (Lauda Ecoline RE220. Brinkman Instruments Inc. NY. USA; ± 0.01 ºC of accuracy). A series of measurements at three radial distances between optical fibers were performed for each experimental design treatment. The distance between fibers was first adjusted to 2 mm. This procedure was repeated at distances 2.5 and 3 mm (Figure 1). Light scatter intensity at the target radial distances was measured at an integration time (*IT*) ranging from 19 to 60 s, where *IT* was the detector light exposure time. The light scattering spectral scans, $I(\lambda)$, were automatically processed by subtracting the respective dark spectral scans and dividing by the *IT* to give the light scattering normalized spectral scans, $I(\lambda)$ (bits s^{-1}). Light scattered by 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). The data acquisition system consisted of a PC connected by a USB port to the spectrometer and programmed for data acquisition with SprectraSuit Spectroscopy platform software.

III. RESULTS AND DISCUSSION

According to Table 2, Pearson correlation coefficients between the emulsion quality metrics and optical measurements were strong in all the parameters studied. As expected, most of the parameters characterizing changes in texture, color and lipid oxidation of cooked emulsions were correlated with many of the optical measurements obtained in the fresh meat emulsions.

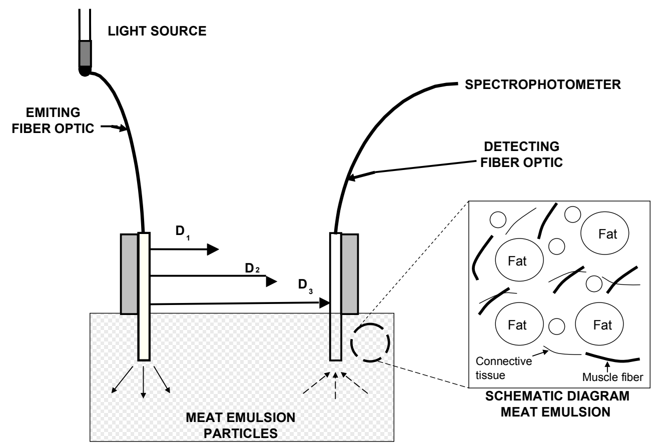

Figure 1. Schematic figure of the optic sensor used to measure light backscatter in meat emulsions

The colour parameters were strongly correlated with the optical parameters (refer for abbreviations to Table 2): $I_{3D2.5}$-C^*_{ab} (R= -0.874, P <0.001), λ_{3D3}-H^o_{ab} (R= - 0.518, P <0.001), I_{3D3}-L^* (R= 0.430, P <0.001), $I_{3D2.5}$-b^* (R= 0.707, P <0.001), $I_{3D2.5}$-a^* (R= 0.813, P <0.001). Furthermore, significant changes in light reflection (P < 0.05) were observed as a result of the different fat levels in fresh frankfurters. Changes in L^* with the fat content were as expected since the increase in the proportion of the whitish fat contributes to the increase in L^*. Logically, the redness values, a*, were inversely proportional to fat content. Reduced protein content (i.e. increased fat to protein ratio) resulted in dilution of myoglobin and consequently a less intense red colour. According to Bañón *et al.* [10], high fat concentration emulsions (0.66 fat/lean ratio) show greater light reflection (larger L^*), and less yellowness/redness than low fat concentration emulsions (0.25 fat/lean ratio). Therefore, the high correlations observed between optical and colour parameters, especially with L^* values, suggest that light backscatter could have potential as indicator of emulsion stability during finely comminuted meat product manufacturing.

Breaking force values (F_B) were strongly (P <0.001) correlated with both normalized intensity (I_{3D3}, R = 0.903, P <0.001) and optical density ($OD_{2D2\text{-}2.5}$, r = -0.893, P <0.001). Similarly, a strong (P <0.001) correlation was observer between I_{3D3} and $TBARS_7$ (r = 0.899).

These findings suggest the feasibility of an optical sensor technology for inline monitoring of physicochemical changes occurring during the meat emulsification process that would improve the meat emulsion stability.

Table 2 Pearson's correlation coefficients between dependent variables obtained by light backscatter at 625 nm, L^*, a^*, H, F_B and TBARS at day7.

	H	F_B	$TBARS_7$	L^*	a^*
I_{3D2}	-0.592^{*}	0.817^{**}	0.792^{**}	0.328^{***}	0.750^{**}
$I_{3D2.5}$	-0.562^{ns}	0.875^{***}	0.822^{**}	0.312^{***}	0.813^{**}
I_{3D3}	-0.681^{*}	0.903^{***}	0.899^{***}	0.430^{***}	0.771^{**}
λ_{3D2}	0.543^{ns}	-0.832^{***}	-0.658^{*}	-0.521^{*}	-0.637^{*}
$\lambda_{3D2.5}$	0.583^{*}	-0.873^{***}	-0.750^{**}	-0.486^{*}	-0.726^{**}
λ_{3D3}	0.381^{ns}	-0.545^{ns}	-0.474^{ns}	-0.283^{**}	-0.545^{ns}
$OD_{2D2\text{-}2.5}$	0.404^{ns}	-0.893^{***}	-0.752^{**}	-0.237^{**}	-0.761^{**}
$OD_{2D2\text{-}3}$	0.384^{ns}	-0.707^{**}	-0.811^{**}	-0.111^{**}	-0.730^{**}

IN = 12. ns Not significant, *P<0.05, **P<0.01, ***P<0.001. L*, lightness; a*, redness; H, hardness; FB, breaking force; TBARS7, TBARS day 7. I3D2, normalized light backscatter intensity peak 3 distance 2; I3D2.5, normalized light backscatter intensity peak 3 distance 2.5; I3D3, normalized light backscatter intensity peak 3 distance 3; λ3D2, wavelength at the maximum intensity for peak 3 distance 2; λ3D2.5, wavelength at the maximum intensity for peak 3 distance 2.5; λ3D3, wavelength at the maximum intensity for peak 3 distance 3.OD, optical density; OD2D2–2.5, optical density between distances 2 and 2.5; OD2D2–3, optical density between distances 2, 3.

IV. CONCLUSION

Light propagation was found to decrease as distance, *HPP* percentage increased, and Fat percentage decreased. High correlation between light backscatter parameters generated during the comminuting process with color coordinates ($I_{3D2.5}$-a^*: R= 0.813) breaking force ((F_B- I_{3D3}: R= 0.903, P <0.001) and *TBARS* (*TBARS*- I_{3D3}: R= 0.899, P <0.001) of the frankfurters were found. The results obtained suggest that the optimum sensor configuration for an optical meat emulsion stability sensor would use multiple measurements groups (i.e., detecting fibers surrounding an emitting fiber with a radial distance < 2.5 mm). It could be concluded that the development of an inline light scatter sensor and the proposed optical measurement system will maximize the final cooked sausage quality.

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