71st ICoMST
GIRONA - CATALONIA - SPAIN
3rd-8th August - 2025

# PREDICTING THE STABILITY OF FUNCTIONAL SAUSAGES WITH CAROB USING LIGHT BACKSCATTER FIBER OPTIC SENSOR

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## I. INTRODUCTION

According to Barbut [1], fat stabilization during the chopping of meat emulsions, such as those used in frankfurters, occurs through the formation of a protein film surrounding the fat particles. This film helps to retain fat within the protein matrix. During the chopping process, various attractive forces act to bind the raw materials, contributing to the formation of a uniform and cohesive emulsion structure [2]. The food industry needs new methods for analyzing meat emulsion quality to complement traditional techniques. One such approach involves using light-scatter measurements to assess the stability of meat emulsions during sausage production. Introducing real-time sensor technology capable of identifying the optimal level of fat emulsification and overall emulsion stability—ensuring maximum stability and minimal cooking losses—could significantly improve the emulsification process [3-4]. This would not only enhance the texture of the cooked sausage but also reduce cooking losses, leading to more consistent final products, better quality, and economic benefits. The aim of this study was to investigate whether the light backscatter response from fresh pork meat emulsions with Carob as source of protein is linked to the stability characteristics of the final product.

## II. MATERIALS AND METHODS

In this study, a specially designed fiber optic measurement system along with a miniature fiber optic spectrometer to measure the intensity of light scatter across wavelengths from 300 to 1100 nm was used. Measurements were taken at different radial distances (2, 2.5, and 3 mm) from the light source in pork emulsions prepared with two fat levels (12% and 25%) and two levels of carob protein CP) - 0% and 2.5% by duplicated. These conditions were chosen to evaluate the effects on emulsion breakdown and lipid oxidation. In total, 12 tests were carried out (N = nab = 3 × 2 × 2) by duplicated, in total 24 test. Several quality indicators of the final product (technological dependent variables) were measured to assess lipid oxidation—using thiobarbituric acid-reactive substances (TBARS)—and emulsion stability, based on parameters like hardness, cohesiveness, deformability, and breaking force of the cooked meat emulsions. Light backscatter profiles were collected from fresh pork emulsions using a custom-built laboratory-scale optical sensor. Two small plastic probes were constructed to detect scattered light from the sample using a High-Resolution Fiber Optic Spectrometer (Model HR4000, Ocean Optics, Inc., Dunedin, FL, USA). The light source was a tungsten halogen bulb (LS-1, Ocean Optics, Inc.), covering a wavelength range of 300–1100 nm. Fiber optic cables, made with 600 µm diameter fibers (Spectran Specialty Optics, Avon, CN, USA), connected the probes to the spectrometer and light source via SMA connectors. Before measurements, the fiber tips were aligned vertically at the same height and adjusted horizontally, then immersed 12.7 mm into the emulsion. Sample temperature was precisely maintained using a water bath (Lauda Ecoline RE220, Brinkman Instruments Inc., NY, USA) with ±0.01 ºC accuracy. Light scatter intensity was recorded over integration times (IT) ranging from 15 to 70 seconds, which determined the sensor's exposure duration. The spectral data, I(λ), were processed by subtracting background (dark) scans and dividing by the IT, producing normalized spectral scans in bits per second. The scattered light from the emulsion matrix was transmitted via the receiving fiber to the spectrometer, and data were collected using the SpectraSuite software via a USB-connected PC.

## III. RESULTS AND DISCUSSION

The results showed (Table 1) that several optically measured parameters were significantly correlated with emulsion stability. Specifically, light backscatter intensity was directly related to breaking force, color, and TBARS values. Building upon the most significant correlations identified, this study proposes an optimized optical measurement configuration that mitigates the effects of inherent variability in emulsions, thereby improving the reliability of the association between optical signals and quality indicators within processing technologies. The color parameters

showed strong correlations with the optical measurements (see Table 1 for abbreviations): I3D2.5 was highly correlated with Hºab, λ3D3 with Hºab, $I3D_3$ with L, I3D2.5 with $F_B$*, and I3D2.5 with a*. Additionally, significant differences in light reflection ($P < 0.05$) were observed depending on the fat content in fresh frankfurters. As expected, L* values increased with fat content, due to the higher proportion of whitish fat, which enhances lightness. Conversely, redness (a*) decreased as fat content increased. This is likely due to the dilution of myoglobin caused by lower protein levels (i.e., a higher fat-to-protein ratio), leading to a less intense red color. According to Bañón et al. [5], high-fat emulsions (fat/lean ratio of 0.66) reflect more light (higher L* values) and display less yellowness and redness compared to low-fat emulsions (fat/lean ratio of 0.25).

Table 1. Pearson's correlation coefficients between dependent variables obtained by light backscatter at 625 nm, *L**, *a**, *H*, $F_B$ and TBARS at day6.

| | *H* | $F_B$ | $TBARS_6$ | *L** | *a** |
|---|---|---|---|---|---|
| $I_{3D2}$ | -0.592$^{*}$ | 0.737$^{**}$ | 0.792$^{**}$ | 0.328$^{***}$ | 0.650$^{**}$ |
| $I_{3D2.5}$ | -0.562$^{***}$ | 0.875$^{***}$ | 0.822$^{**}$ | 0.312$^{***}$ | 0.713$^{**}$ |
| $I_{3D3}$ | -0.681$^{*}$ | 0.903$^{***}$ | 0.899$^{***}$ | 0.330$^{***}$ | 0.671$^{**}$ |
| $\lambda_{3D2}$ | 0.543$^{ns}$ | -0.832$^{***}$ | -0.558$^{*}$ | -0.521$^{*}$ | -0.537$^{*}$ |
| $\lambda_{3D2.5}$ | 0.583$^{*}$ | -0.873$^{***}$ | -0.750$^{**}$ | -0.486$^{*}$ | -0.526$^{**}$ |
| $\lambda_{3D3}$ | 0.781$^{ns}$ | -0.545$^{ns}$ | -0.374$^{ns}$ | -0.283$^{**}$ | -0.645$^{ns}$ |
| $OD_{2D2\text{-}2.5}$ | 0.304$^{ns}$ | -0.993$^{***}$ | -0.552$^{**}$ | -0.237$^{**}$ | -0.861$^{**}$ |
| $OD_{2D2\text{-}3}$ | 0.384$^{ns}$ | -0.707$^{**}$ | -0.811$^{**}$ | -0.111$^{**}$ | -0.830$^{**}$ |

IN = 12. ns Not significant, *P<0.05, **P<0.01, ***P<0.001. L*, lightness; a*, redness; H, hardness; FB, breaking force; TBARS6, TBARS day 6. 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 observed to decrease with increasing radial distance between fibers, higher levels of high-pressure processing (HPP), and decreasing fat content. Strong correlations were identified between light backscatter parameters measured during the comminution process and key product quality indicators: I3D2.5 showed a high correlation with redness (a*) ($R = 0.713$), while I3D3 was strongly correlated with breaking force ($R = 0.903$, $P < 0.001$) and TBARS values ($R = 0.822$, $P < 0.001$), indicating lipid oxidation. These findings suggest that the optimal configuration for an optical sensor aimed at assessing meat emulsion stability would involve multiple detection points (i.e., detecting fibers arranged around an emitting fiber at a radial distance of less than 2.5 mm). It can be concluded that the development of an inline light-scatter sensor using this optical setup has the potential to significantly enhance the quality control of functional cooked sausage products with Carob.

## ACKNOWLEDGEMENTS

This study is part of the Agroalnext programme under the project BiocarnIA and has been supported by the MCIU with funding from the European Union Next Generation EU (PRTR-C17.I1) and by the Autonomous Community of the Region of Murcia-Fundación Seneca.

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