Optical determination of fiber orientation and anisotropy of plant based high-moisture meat analogues

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Meat is a highly hierarchically structured material and many of the textural properties of meat are highly dependent on its internal structure both micro and macroscopically. For high-moisture meat analogues, in addition to textural properties, fiber structure is a key factor in consumer acceptance. The mechanical performance of the final material is affected by the length of the fibers, their thickness and orientation, as well as by the adhesion between the fibers and the matrix. Although several techniques have been developed to quantify fiber formation in extrudates, their application for real-time quality control in industrial processes is challenging. In the present study, we tested a simple and easy-to-implement non-destructive optical method that quantifies fiber structure and anisotropy in plant-based high-moisture meat extrudates. According to the continuous-time random walk theory, light propagation anisotropy is a distinctive optical property of any material caused by preferentially oriented microstructures such as fibers that scatter or transmit light propagation. It is therefore possible to determine the level of matrix structuration by measuring the anisotropy of light propagation through a given fibrous material. For samples with a more isotropic structure, the light transmission probabilities are equal in all directions, resulting in a circular light scattering pattern. On the other hand, a direction with a minimum value of light scattering can be related to the direction of fiber orientation, which forms a reflection ellipse with the main axes oriented in the direction of the fiber. A modified image processing method was used to extract information about the level of anisotropy of the illuminated samples. Iso-intensity contour plots were used to describe the anisotropy of light propagation, as they represent the range of propagated light of equal intensity. The resulting iso-intensity contours were processed to obtain shape descriptor information, provided that a perfect circle represents an isotropic structure and a highly elongated ellipse represents an anisotropic structure caused by different levels of fiber orientation. The results were in good agreement with data obtained by confocal laser scanning microscopy, where the same fibrous structures were also visualized and quantified.