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3D PRINTING OF MEAT-BASED FOODS - RHEOLOGICAL SELECTION CRITERIA

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I. INTRODUCTION

The proportion of elderly people in the world is increasing (1), leading to a rise in age-related physiological disorders such as oral decline, dysphagia or undernutrition (2). At present, few meat products have a texture suitable for oral decline. 3D printing makes it possible to adapt this texture to ensure a sufficient supply of good-quality protein (3). However, it is necessary to establish selection criteria based on rheological properties to select meat-based formulations for 3D printing. In complement, ingredient such as NaCl or flax mucilage can have an effect on texture and printability.

II. MATERIALS AND METHODS

Various rheological parameters were measured or calculated to determine the most suitable formulations for 3D printing. (Fig. 1). Only the results based on two of them are described here: Extrusion difficulty and shear thinning behaviour.

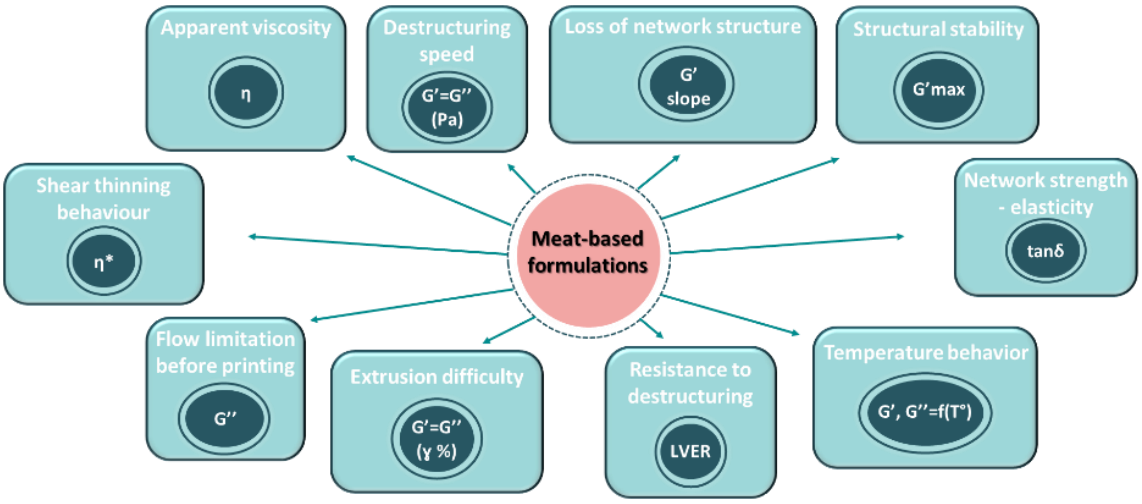


Figure 1. Influential rheological parameters for printability criteria.

Two *Semitendinosus* muscles extracted from Charolais cow were ground using a ball mill after cooling with liquid nitrogen. The mucilage was extracted from flax seeds (*Linum flavum L.*) by incubation in boiling water. Ground meat may or may not have NaCl or mucilage added. The 4 conditions used are described below.
Composition of the different formulations prepared for the evaluation of printability properties: PM - Pure Meat (meat 100%); SM - Salted Meat (meat 98.5% + NaCl 1.5%); MM6 - Meat + Mucilage (meat 94% + 6% mucilage); MM18 - Meat + Mucilage (meat 82% + 18% mucilage).
The rheological behavior of the matrices was determined with a HAAKE MARS iQ Air rheometer (Thermo Electron GmbH, Germany) fitted with a 35-mm-diameter striated plane–plane geometry with a gap of 1 mm, at 20 °C ± 1 °C. Statistical analyses were performed using Statistica 14.0.015 (Tibco Software Inc., USA). Data were analyzed using the Grubbs test to detect outliers. Depending on the data, different statistical tests were used: repeated measures analysis of variance (ANOVA), respecting the conditions of normality and homoscedasticity of the samples; Tukey's test was used for *post-hoc* multiple comparisons, the level of significance being set at $P < 0.05$. Results were expressed as means ± standard error of the mean (SEM).

III. RESULTS AND DISCUSSION

The extrusion difficulty is an important parameter for assessing the printability of a formulation. Crossing the curves G' and G'' (flow point) as a function of shear stress (γ %) enables us to classify the various formulations according

to this parameter. Formulations containing the most water content have a higher extrusion capacity, notably due to lower viscosity. The most structured formulations (PM and SM) are the most difficult to extrude (significant differences at the G' = G'' crossover) (Fig. 2a). Even if extrusion is possible, the resulting filament is discontinuous and poorly respects the 3D geometry, confirming the fact that the printing capacity of meat is bad (4).
Shear-thinning behavior is considered a key parameter for the success of the food 3D printing process (4). The complex viscosity (η*) allows to discriminate formulations according to their thinning capacity. η* was calculated from the Cox-Merz model during a frequency sweep, where the sample is not destructured.
Fig. 2b shows that, for all formulations, η* decreases as the frequency (ω) increases. This indicates that shear-thinning behavior is associated with flow during extrusion (fluid movement is initially difficult at slow strain rates, but flows more freely at high rates) and the absence of shape deformation after printing. Any food matrix with these characteristics can be extruded, as filament formation is possible. Formulations containing high amounts of mucilage (18%) show lower viscosities at low frequencies, indicating that flow is favored from the start of extrusion. These results agree with those obtained by (4) on meat-based products. This behavior would reflect a repositioning of polymer chains for realignment as well as post-printing stability, making the formulations suitable for extrusion 3D printing (5).

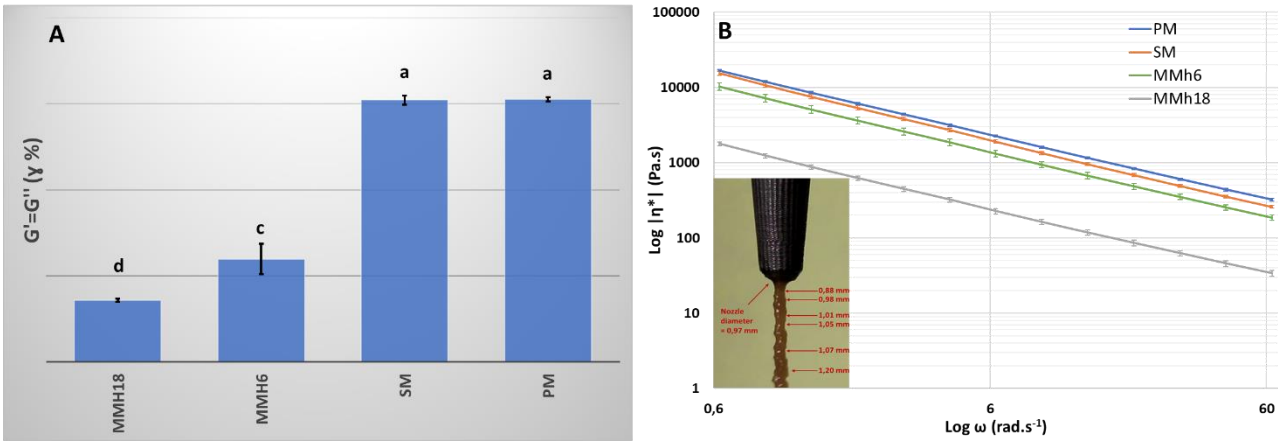


Figure 2. Examples of rheological parameters used for detemining printability of meat-based formulations (PM - Pure Meat (meat 100%); SM - Salted Meat (meat 98.5% + NaCl 1.5%); MM6 - Meat + Mucilage (meat 94% + 6% mucilage); MM18 - Meat + Mucilage (meat 82% + 18% mucilage)). A - Ranking of formulations according to their extrusion difficulty (G' = G'' - critical strain, γc, as a function of the shear strain γ %). B - Visualization of the shear-thinning behavior of different formulations by representing their complex viscosity as a function of the angular frequency. The associated image illustrates the shear-thinning phenomenon of a pure meat matrix (PM) following extrusion through a 0.97 mm diameter nozzle, at a speed of 2.08 mm.min^{-1}. Error bars correspond to SEM, calculated from 3 repetitions. Identical letters mean no significant difference between formulations (P > 0.05).

IV. CONCLUSION

Based on the 10 rheological parameters presented in Fig.1, it appears that hot-extracted mucilage can be added to a meat preparation to improve its printability properties. A concentration of 18%, despite a good extrusion capacity, seems to degrade the structuring and self-supporting capacity of the matrix. On the other hand, a concentration of 6% seems to be an interesting alternative, given the intermediate rheological behavior of this formulation, but also depending on the moderate nutritional impact it has on the meat.

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