Journal of Food Engineering 220 (2018) 101–108

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Investigation on fish surimi gel as promising food material for 3D printing

Lin Wang [a], Min Zhang [a, b, *], Bhesh Bhandari [c], Chaohui Yang [d]

[a] State Key Laboratory of Food Science and Technology, Jiangnan University, 214122, Wuxi, Jiangsu, China
[b] Jiangnan University(Yangzhou) Food Biotechnology Institute, Yangzhou, 225002, China
[c] School of Agriculture and Food Sciences, University of Queensland, Brisbane, QLD, Australia
[d] Yangzhou Yechun Food Production & Distribution Co., Yangzhou, 225200, Jiangsu, China

ARTICLE INFO

Article history:
Received 29 September 2016
Received in revised form
22 February 2017
Accepted 27 February 2017
Available online 27 March 2017

Keywords:
3D gel-printing
Surimi gelation
Additive manufacturing
Rheological properties
Printing parameters

ABSTRACT

This paper presents the development of a new 3D printing food constructs based on fish surimi gel system. This study investigated the influence of NaCl addition on rheological property, gel strength, water holding capacity (WHC), water distribution and microstructure of surimi gel to be used as a material for 3D printing. The obtained results from rheological studies showed that the surimi gels made with 1.5 g NaCl/100 g surimi mixture can be used for 3D printing. NaCl addition is helpful for the slurry to flow out from the nozzle in time and then get viscous post-deposition for holding its shape. Moreover, the effects of the printing parameters on the geometrical accuracy and dimension of the printed surimi gel were also studied. In this particular printing system, the 2.0 mm nozzle diameter, 5.0 mm nozzle height, 28 mm/s nozzle moving speed and 0.003 cm^3/s extrusion rate were the optimal parameters to print 3D samples with fine resolution, better matching with the target geometry, fewer point defects and no compressed deformation. The overall results suggested that the 3D printing based on surimi gel system is a promising method for producing complexed-shape food patterns.

1. Introduction

Additive manufacturing (AM), commonly referred to as 3D printing, has received a large amount of attention from industry, academia and the public due to its numerous advantages. It offers shorter production runs compared with traditional manufacturing methods. In addition, it can generate various complex shapes by using limited mass of materials with an enhancement of mechanical properties (Godoi et al., 2016). 3D printing, a process that emerged as a distinct AM technique in recent years, involves the extrusion of a melted filament or paste through a fine nozzle while the nozzle's position is computer-controlled in accordance with a shape design model. This allows the manufacturing of complex objects, practically unhindered by design complexity, thus providing substantial liberty in new and untested geometric designs (Ivanova et al., 2013; Kalsoom et al., 2016).

For food sector, 3D printing provides a new frontier in food processing. It helps us to realize and produce new foods with complicated shapes using particular material formulation mixtures. The purpose of applying AM technology to printing food materials is to simplify the production process and combine the design of a food with new textures and potentially enhance its nutritional value (Pallottino et al., 2016). In recent years, some researchers have been reported to adapt the AM technology to the design of various food constructs like chocolate or meat products (Hao et al., 2010; Lipton et al., 2010). Lipton et al. (2010) used transglutaminase and bacon fat as additives to make printable scallop and turkey meat-puree. These final meat products well kept their shape after cooking. Sun et al. (2015) reported the possibility of printing cookies from a mixture of sugars, starch and mashed potato without the need of further post-processing (cooking). Some groups have also investigated the effects of printing parameters on the geometrical accuracy and dimension of food pattern. Hao et al. (2010) demonstrated a linear relationship between the extrusion rate used in the ChocALM software and the bead diameters obtained.

The properties and composition of food materials have been considered to be the most important factors in 3D printing process. These materials should be homogenous and have appropriate flow

* Corresponding author. School of Food Science and Technology, Jiangnan University, 214122, Wuxi, China.
E-mail address: min@jiangnan.edu.cn (M. Zhang).

http://dx.doi.org/10.1016/j.jfoodeng.2017.02.029
0260-8774/

properties for extrusion as well as can support its structure during and after printing process (Godoi et al., 2016). In a multicomponent system, the change of proteins, carbohydrates, fat/oil and water will affect the melting behavior and plasticization of the food-materials during 3D printing processes. The plasticization lowers the glass transition temperature of food polymers, such as starch, proteins and carbohydrates (Bhandari and Roos, 2003) making them a viscous printable material.

Surimi is a typical intermediate fish product. Gelation of surimi is induced by the denaturation of protein and the subsequent aggregation of the unfolding protein (Cando et al., 2015; Jin et al., 2011). New textures can be created via surimi gelation mechanism with gelatin, alginate and other polysaccharides governed by both partical based-gelation and hydrogel-forming mechanisms (Tahergorabi and Jaczynski, 2012). Sodium chloride is commonly used to solubilize the myofibrillar proteins and to induce the protein unfolding. The final gels exhibited different rheological properties as the different amount of NaCl added (Cando et al., 2015).

The surimi is a viscous food gel system and that can be a promising food material for developing various 3D constructs. The main aim of this work is exploring the opportunity of 3D printing of a surimi mixture. In this work, the effects of nozzle diameter size (0.8, 1.5, 2.0 mm), nozzle height (5, 10, 15, 20 mm), nozzle moving speed (20, 24, 28, 32 mm/s), extrusion rate (0.002, 0.003, 0.004, 0.005 cm^3/s) and material properties of surimi slurry induced by different concentrations of NaCl (0, 0.5, 1.0, 1.5 g/100 g) on the extrusion behavior and final qualities of the 3D constructs were investigated.

2. Materials and methods

2.1. Surimi sample preparation

Fresh silver carp fillet was purchased at a local market in Wuxi city, China. The fish fillet was minced using a mechanical mincer (Model UM 5, Stephan Machinery Co., Hameln, Germany) with an orifice diameter of 4 mm. The minced fish was then washed with cold water (4 °C) using a mince/water ratio of 1:3 (v/w). Washing was performed twice, and the washed mince was centrifuged at 700 g for 15 min at 4 °C. Surimi moisture and pH were 82% and 6.8, respectively. Surimi mince was mixed with NaCl at different levels (0, 0.5, 1.0, 1.5, 2.0% w/w) in a mixer HSN-29 (Wuzhe Food Machine Co., Ltd, Wuzhe Town, Guangdong, China). The temperature of the mixture was kept below 5 °C during mixing.

2.2. Testing of material properties

2.2.1. Rheological characterization

The rheological properties of the mixed surimi slurry at different NaCl levels were characterized using a AR-G2 Rheometer (AR-1000, Co. TA, USA) with a parallel plate (diameter = 20 mm), at 25 °C. The gap between two plates was set to 2.0 mm. For determination of steady shear viscositie, shear rate was ramped from 0.1 to 100 s^{-1}. Shear stress, shear rate, and steady shear (apparent) viscosity (η) were recorded by a RheoWin 4 Data Manager (Rheology Software, Thermo Fisher Scientific, Waltham, MA).

Dynamic viscoelastic properties were characterized using small-amplitude oscillatory frequency sweep mode. The frequency was oscillated from 0.1 to 100 rad/s, and all measurements were performed within the identified linear viscoelastic region and made at 0.4% strain. The elastic modulus (G′), loss modulus (G″), and loss tangent (tan δ) were recorded. All tests were repeated three times.

2.2.2. Gel strength

The gel strength of the surimi gels was measured using a cylinder measuring probe (P/0.5) attached to a TA. TX2 texture analyzer (TA-XT plus, Stable Micro Systems, Ltd., Surrey, UK) at a constant probe speed of 1.0 mm/min at room temperature (25 ± 1 °C). The gel strength is defined as the initial force required to disrupt the gels. Experiments were conducted in triplicate for each type of sample.

2.2.3. Water holding capacity (WHC)

WHC values of the surimi gels were determined according to the method of Zhang et al. (2015) with slight modifications. Samples (3 g) were centrifuged at 8,000 g for 30 min at 4 °C and the WHC (%) was expressed as the final weight of the centrifugate as a percentage of the weight before centrifugation.

2.2.4. Microstructure

Scanning electron microscopy (SEM) was performed to examine the structural characteristics of surimi gels (Quanta-200, FEI Ltd., Netherlands) according to the method described by Liu et al. (2008) with slight modifications. Gel samples ($3 \times 3 \times 3$ mm^3) were fixed in 0.1 M phosphate buffer (pH 7.0) containing 2.5% glutaraldehyde for 24 h at 4 °C, and then post-fixed in the buffer containing 1% osmium tetraoxide for 5 h at 4 °C. Samples were washed 3 times with 0.1 M phosphate buffer, dehydrated in graded ethanol series of 50, 70, 80, 90and 100% (v/v), and then vacuum-freeze-dried.

2.2.5. Low frequency-NMR relaxation measurements

The ^1H NMR measurements were carried out using a NMR spectrometer (PQ001, Niumag Electric Corporation, Shanghai, China) at 100 KHz, connected with an external circulating cryostat bath to control the sample temperature in the magnet chamber. Surimi sample was tightly packed up to 6 cm into a NMR sample tube with diameter of 10 mm, and put into the chamber. Transverse (T_2) relaxation was measured using the Carr-Purcell-Meiboom-Gill pulse sequence (CPMG) with 4 scans, 3000 echoes, 13.8 s between scans, and 200 μs between pulses of 90° and 180°. The data were analyzed by applying multi-exponential fitting of T_2 relaxation data with the MultiExp Inv Analysis 4.09 (Niumag Electric Corporation, Shanghai, China).

2.3. Printing process

The 3D printing system composed of the following three major parts: (i) feed hopper with auger mixer and conveyor, (ii) an extrusion system, (iii) and a X-Y-Z positioning system using stepper motors. The nozzle height (5, 10, 15, 20 mm) from the printing bed was achieved by adjusting the whole feeding device. The pressure exerted on the surimi was applied via the extruder conveying screw. The surimi samples were extruded onto a polished transparent plastic polymer plate using nozzles of circular shape with diameters of 0.8, 1.5 and 2.0 mm. The printing process was conductued at rome temperature (25 °C). The motion and positioning control were provided by a computer with a specifically designed Java program and micro controller.

To assess the effects on the extrudate geometry, line tests were used. Lines of surimi gel were extruded at varying extrusion rates, for different movement rates and the diameter of these lines was then measured (Fig. 9). The line test samples were then cut to a known length and weighed.

2.4. Statistical analysis

Analysis of variance was performed and mean comparisons were run by Duncan's multiple-range test using the SAS system for Windows 9.0 (SAS Institute, Cary, NC). Significant differences ($p < 0.05$) between mean values of samples were determined.