Food Research International 106 (2018) 666–676

Contents lists available at ScienceDirect

Food Research International

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

On printability, quality and nutritional properties of 3D printed cereal based snacks enriched with edible insects

C. Severini*, D. Azzollini[1], M. Albenzio, A. Derossi

Department of Science of Agriculture, Food and Environment, University of Foggia, Italy

ARTICLE INFO

Keywords:
3D food printing
Edible insects
Tenebrio molitor
Microstructure
In-vitro protein digestibility

ABSTRACT

3D printing technology was employed to obtain snacks with a designed cylindrical geometry from wheat flour dough enriched by ground larvae of Yellow mealworms (*Tenebrio molitor*) as novel source of proteins. The main microstructural features, overall quality, and nutritional attributes were studied as a function of formulation, time and temperature of baking. The addition of ground insects up to 20 g/100 g (d.b.) resulted in softer dough. This caused an overflow in dough deposition producing the increase in diameter, height and weight of snacks. Baking conditions did not alter the overall aspect of the snacks, but modification of the main dimensional and microstructure attributes were observed due to the better water evaporation. The optimization of baking conditions found that 22 min and 200 °C allowed obtaining a maximum desirability of 0.693. Baked in these conditions, the printed snacks enriched with 10 and 20% of ground insects significantly increased the total essential amino acid, from 32.5 (0% insects) to 38.2 and 41.3 g/100 g protein, respectively. The protein digestibility corrected amino acid score increased from 41.6 to 65.2 from 0 to 20% insect enrichment, with lysine and methionine + cysteine being the respective limiting amino acid. Our results evidenced the rational promotion of insects based on nutritional arguments and validated the use of 3D printing as technology to manufacture innovative printed snacks without adverse impact on technological quality.

1. Introduction

Edible insects have been recognized as a sustainable source high-value animal proteins, bearing the potential to help satisfying the raising demand of meat products (van Huis, 2013). The protein content of insects ranges from 40 to 75 g/100 g on dry weight basis, mainly depending on the species and the stage of life cycle (Verkerk, Tramper, van Trijp, & Martens, 2007). Thanks to their wide micronutrient variations, insects could also serve as equivalents of shellfish, nuts and pulses (Raubenheimer, Rothman, Pontzer, & Simpson, 2014). Globally, around 2 billion people eat almost 1900 species of insects as part of their diet, particularly in Asia, Africa and South America (FAO, 2013). Contrariwise, in parts of the world, where the consumption of insects is not traditional, such as Europe and North America, consumer's negative perception is identified as a barrier to their widespread adoption (Deroy, Reade, & Spence, 2015; Looy, Dunkel, & Wood, 2014; Shelomi, 2015; Tan et al., 2015). To overcome the disgust of Western consumers, most of the existing research has focused on rational promotion through ethical and nutritional arguments (De Boer, Schösler, & Boersema, 2013), identification of psychological individual traits (Schösler, de Boer, & Boersema, 2012; Tan, van den Berg, & Stieger, 2016; Verbeke, 2015), sensory appeal and appropriateness of developed food product (Caparros Megido et al., 2014; Tan et al., 2015). Recently, Tan et al. (2016) confirmed that presenting insects invisibly into familiar food carriers increases their acceptability. Not surprisingly, researches are being performed on the quality of dry forms of insects (Azzollini, Derossi, & Severini, 2016) and their extracts (Bußler et al., 2016; Yu, Ramaswamy, & Boye, 2013; Zhao, Vázquez-Gutiérrez, Johansson, Landberg, & Langton, 2016). At the same time, though, since familiarity arises sensory expectations, the combination of insects with a carrier perceived as inappropriate, could result in low consumption intentions. Therefore, alongside socially aware marketing campaigns and advances in processing practices, the design of appropriate insect products with no sensory expectations is a critical factor. To this aim, 3D printing has been recognized as an important tool at disposal of edible insect industries (Payne et al., 2016).

3D printing, better known as additive manufacturing (AM), is an innovative process of fabrication where a process of digitally-controlled robotic construction can make three-dimensional objects based on a layer-by-layer deposition. AM refers to a group of three main

* Corresponding author.
E-mail address: carla.severini@unifg.it (C. Severini).
[1] Current address: Food Quality and Design Group, Department of Agrotechnology and Food Sciences, Wageningen University, P.O. Box 17, 6700 AA Wageningen, The Netherlands.

https://doi.org/10.1016/j.foodres.2018.01.034
Received 27 November 2017; Received in revised form 16 January 2018; Accepted 17 January 2018

technologies classified as selective binding, selective solidification and selective deposition. Engineering, manufacturing and medicine are key areas where AM is driving major innovations (Campbell, Williams, Ivanova, & Garrett, 2012). Besides, food production is also an area with large potential for industrial and home applications of 3D printing (Lipton, Cutler, Nigl, Cohen, & Lipson, 2015; Pallottino et al., 2016; Sun, Zhou, Huang, Fuh, & Hong, 2015; Wegrzyn, Golding, & Archer, 2012). Among numerous applications, additive food manufacturing (AFM) is becoming popular thanks to the possibility to design foods with appealing forms, new textures and personalized nutritional values (Severini & Derossi, 2016; Yang, Zhang, & Bhandari, 2015). Perhaps thanks to its low cost and ease of use, in AFM, the selective deposition has become the most widely studied technology. By this technology, a soft-material formulated of edible ingredients is loaded into a cylinder and extruded in consecutive layers through a nozzle by force of a piston (Godoi, Prakash, & Bhandari, 2016). Aregawi et al. (2015) applied the selective deposition system to print cookies with a honeycomb structure, while Lipton et al. (2010) printed a cube with a deconstructed meat paste with the aid of transglutaminase enzyme. Severini and Derossi (2016) obtained snacks with different texture by printing wheat dough with designed values of porosity. Severini, Derossi, Ricci, Caporizzi, and Fiore (2017) obtained 3D printed edible objects based on a blend of fruit and vegetables. The European PERFORMANCE project employed the same technology to design 3D printed soft meals for older people who have difficulties with swallowing (Fp7, 2016). Moreover, an example of 3D printing technology applied to edible insects is represented by Soares and Forkes (2014), who printed larvae of Yellow mealworms (*T. molitor*) in combination with fondant to produce icing for top cakes' decoration.

Larvae of Yellow mealworms have been commercially farmed for human consumption in many regions of the world (Kim, Setyabrata, Lee, Jones, & Kim, 2016). Furthermore, in countries such as USA, Canada, Mexico, Belgium and the Netherlands, dry powders of Yellow mealworm larvae or their derivatives can already be found in the market (Dossey, Morales-Ramos, & Rojas, 2016). The design of 3D printed foods containing Yellow mealworm larvae may help to fully realize their potential and contribute to improve the nutritional value of familiar raw food matters.

In this paper, we investigated the printability and technological characteristics of 3D printed snacks obtained with wheat flour dough substituted with different amounts of Yellow mealworm powder. The effects of mealworm powder and baking conditions on some physical properties and microstructure of snacks were analyzed. Furthermore, the nutritional value, protein digestibility and amino acid profile were compared among snacks obtained at different levels of substitution.

2. Materials and methods

2.1. Dough preparation and experimental design

Wheat flour of type 0 was provided by Molino Taramazzo (Pezzolo Valle Uzzone, Cuneo, Italy). Microwave-dried larvae of Yellow mealworms were supplied by HaoCheng Mealworm Inc. (Xiangtan, Hunan, China) and ground for 60 s at 6000 rpm in a knife mill (Grindomix GM 200, Retsch, Germany) to pass through 900 μm sieves. Three blends of wheat flour and mealworm powder were formulated in mass ratios of 100:0, 90:10 and 80:20 on a dry matter basis. A Box-Behnken design consisting in three independent variables, level of insect substitution (g/100 g flour blend, dry matter basis), baking time (min) and baking temperature (°C), and three levels of variations was used for experiments. A total of 15 experiments were carried out in triplicates. Table 1 shows the coded and uncoded values of independent variables for each experimental condition.

For each blend, a farinograph test was performed according to the standard AACC method 54–21 (Brabender, Duisburg, Germany) to determine dough properties, including the optimal mixing time and water absorption. For experiments, the doughs were mixed in the farinograph to reach the development time and left to rest for 10 min before use.

Table 1
Box-Behnken design describing the experimental conditions used during experiments.

Experiments	Codes			Variables		
	(x_1)	(x_2)	(x_3)	Insect enrichment (%)	Baking time (min)	Baking temperature (°C)
1	−1	−1	0	0	14	200
2	1	−1	0	20	14	200
3	−1	1	0	0	22	200
4	1	1	0	20	22	200
5	−1	0	−1	0	18	180
6	1	0	−1	20	18	180
7	−1	0	1	0	18	220
8	1	0	1	20	18	220
9	0	−1	−1	10	14	180
10	0	1	−1	10	22	180
11	0	−1	1	10	14	220
12	0	1	1	10	22	220
13	0	0	0	10	18	200
14	0	0	0	10	18	200
15	0	0	0	10	18	200

2.2. Production of snacks by 3D printing

3D printing process was performed by using a 3D Printer mod. Delta 2040 (Wasp project, Italy) equipped with the Clay extruder kit 2.00 (Wasproject, Italy). The dough, inserted into a stainless-steel chamber, was pushed by a piston at 4 bar through a plastic tube on the head of extruder. For printing, a 3D cylinder with a diameter of 17 mm and height of 22 mm was designed by using the software Thinkercad (Autodesc, Inc.) (Fig. 1). Then, the model was saved as .stl file format and the slicing software CURA 15.04.2 (Ultimaker B,V., The Netherlands) was used to set the printing variables. More specifically, printing conditions were set as follows: print speed (30 mm/s), travel speed (50 mm/s) layer height 0.5 mm and nozzle size 0.84 mm. An infill value of 15% was chosen to obtain the same infill pattern as in Severini, Derossi, and Azzollini (2016). Since the infill refers to the filling of the inner part of the structure, without considering the external shell the virtual model consists in a cylinder having a volume fraction of solid phase of 36%. The objects were printed on a stainless-steel screen (2 mm mesh) and frozen at −18 °C until being baked in a convection oven (Vitality CE116KT – SAMSUNG, South Korea) at conditions reported in Table 1.

2.3. Morphological and microstructure analyses

Raw 3D printed snacks coming from the three blends of wheat and insect powder were analyzed for their dimensional and microstructure properties, in order to evaluate their printability. After 3D printing, morphological and microstructure properties of snacks were analyzed by X-ray microtomography. Three snacks from each treatment were scanned by a micro-CT scan (SkyScan 1174, Brüker, Kontich, Belgium) by using the following settings: voltage 50 kV, current 800 μA, rotation 360°, rotation step 0.6°, average frame 3, magnification 28.5 μm, exposure time 1600 ms. The projection images were reconstructed using NRecon software (Bruker, microCT, Belgium). 2D and 3D analysis of the samples were performed by using CTAn (Version 1.12.0.0, Bruker, microCt, Belgium). The diameter and height of the snakes were performed on the entire objects as described in Severini et al. (2016). For 3D analysis, a number of 300 cross sectional images were converted to binary scale by Otsu's method and trimmed by using the shrink-wrap function to automatically wrap the original region of interest (ROI) around the boundaries of the sample. Moreover, the size distribution of solid phase of the samples was obtained by using function *structure*