LWT - Food Science and Technology 82 (2017) 464–470

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Brewer's spent grain valorization in fiber-enriched fresh egg pasta production: Modelling and optimization study

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ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form
21 April 2017
Accepted 22 April 2017
Available online 25 April 2017

Keywords:
Brewery
Dietary fiber
Egg albumen
Experimental design
Optimization

ABSTRACT

The aim of this work was to valorize brewer's spent grains (BSG) in the production of a fiber-enriched fresh egg pasta. To improve pasta structure, the addition of egg white powder (EWP) was also evaluated. An inscribed Central Composite Design was developed, ranging BSG from 3 to 25 g/100 g and EWP from 0 to 12 g/100 g. Highly significant models ($p < 0.001$) of different complexity were calculated for all the pasta quality parameters, except for thickness and weight increase during cooking. BSG addition significantly lowered average break strain of pasta with respect to a standard formulation produced without fiber (26 ± 10% *vs.* 54 ± 4%, for raw sheets; 25 ± 8% *vs.* 54 ± 1%, for cooked sheets). On the contrary, the addition of EWP improved mechanical properties of cooked pasta due to the tighter protein network developed by ovalbumin. With the highest EWP amount, break load (6.5 ± 0.4 N) and strain (33 ± 4%) of cooked pasta resulted significantly higher than in sample without EWP (1.4 ± 0.1 N and 18 ± 1%, respectively). Optimization of pasta quality by the desirability function demonstrated that BSG and EWP can be successfully exploited in the production of a fresh egg pasta “source of fiber”, thus contributing to a higher sustainability of the brewing process.

1. Introduction

With the exponential increase of the world population, also the demand for food and energy is hugely increasing. At the same time, the slow progress in the development of an effective waste management leads to the accumulation of food waste. A study referred to 2006 revealed that in the EU almost 90 million tonnes of food waste are generated every year, 39% of which is produced by the manufacturing sector (European Communities, 2011). As regards breweries, a variety of solid waste is generated, consisting of spent grains and hops, trub, sludge, surplus yeast, diatomaceous earth slurry from filtration, and packing materials. In particular, wet brewer's spent grains (BSG) are the residuals after grain mashing and extraction of starch and sugars (Olajire, 2012). The amount of BSG normally produced is about 6.2 kg per 100 L of beer (31% of the original malt weight), accounting for roughly 85% of the total by-products (Reinold, 1997). Considering that beer is the most popular alcoholic beverage worldwide, with an annual production of $1.93 \cdot 10^9$ hL in 2015 (Statistics and facts on the beer industry, 2017), the amount of yearly produced BSG can be estimated in about 12 million tonnes. While preventive measures can be studied in order to reduce the generation of BSG, it is important to deal with the existing accumulated BSG.

The nutritional value of BSG is definitely lower than that of the same amount of dried barley, but the high water content (about 80 g/100 g) makes it easily digestible by livestock. Indeed, BSG have a commercial value as by-products for livestock feed (Olajire, 2012). However, as demonstrated by the economic study by Ben-Hamed, Seddighi, and Thomas (2011), in the case of small breweries, transportation costs can be very high, impairing the economics of BSG use in feed; thus alternative uses than cattle feed may be important to develop. Indeed, due also to the global intense pressure towards green environmental technology in order to promote a higher sustainability of the brewing process, a better valorization of BSG can be of outmost interest for breweries.

Abbreviation list: Adj. R^2, adjusted coefficient of determination; BL_C, break load of cooked pasta; BL_R, break load of raw pasta; BS_C, break strain of cooked pasta; BS_R, break strain of raw pasta; BSG, brewer's spent grains; dm, dry matter; EWP, egg white powder; ML, matter loss during cooking; Pred. R^2, predicted coefficient of determination; R^2, coefficient of determination; YM_C, Young modulus of cooked pasta; YM_R, Young modulus of raw pasta.

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http://dx.doi.org/10.1016/j.lwt.2017.04.068
0023-6438/

Several attempts have been made in utilizing BSG for the production of value-added compounds (e.g., xylitol, lactic acid, vitamins, and antioxidants), as growth medium for microorganisms and enzymes production, as raw material for extraction of sugars and proteins, for energy production, and as adsorbent for removing organic materials from effluents and immobilization of various substances (Alyiu & Bala, 2011; Mussatto, Dragone, & Roberto, 2006). Nevertheless, due to the high levels of dietary fiber (around 70 g/100 g dry basis), protein (about 20 g/100 g dry basis) and particularly essential amino acids, as well as appreciable levels of lipids, minerals, polyphenols and vitamins, BSG can also serve as an attractive adjunct in human nutrition (Mussatto et al., 2006). Actually, the incorporation of these compounds into human diets may provide a number of benefits by lowering the risk of certain diseases including cancer, gastrointestinal disorders, diabetes, obesity and coronary heart disease (Fastnaught, 2001).

Cereal-based foods are of primarily importance in human nutrition, since they represent 30–70% of daily energy intake (WHO/FAO, 2003). Numerous attempts to produce cereal foods with improved physiological effects promoting the long-term maintenance of health have been carried out. In this scenario, BSG were successfully incorporated into a number of bakery products, including breads, muffins, cookies, mixed grain cereals, fruit and vegetable loaves, cakes, waffles, pancakes, tortillas, snacks, doughnuts and brownies. Nevertheless, because of the brown color and alterations in the flavor and physical properties (e.g., texture) of the final products, only relatively small quantities (5–10 g/100 g) have been incorporated (Mussatto et al., 2006). As for other complex foods, there is a need to study cereal model systems and build models for the representation of their structure/property relationships in order to understand how they will be modified by the addition of bran and dietary fiber and accelerate the development of consumer-friendly products (Poutanen, Sozer, & Della Valle, 2014).

To the best of our knowledge, studies on BSG addition in fresh egg pasta have not yet been carried out. However, pasta is second only to bread in world consumption, mainly because of its low cost, ease of preparation, versatility, long shelf life, as well as nutritional and sensory properties. Egg pasta is a very popular food, with a growing market and good development possibilities both in Europe and in the United States (Alamprese, 2017). Previous studies investigated the effect of novel ingredient incorporation in pasta in order to enhance its nutritional properties. Irrespective the kind of ingredient, the most important changes were usually related to cooking and structural properties of pasta (Fan, Ma, Wang, & Zheng, 2016; Fukuzawa, Ogawa, Nakagawa, & Adachi, 2016; Lu, Brennan, Serventi, Mason, & Brennan, 2016; Sandhu, Simsek, & Manthey, 2015).

The aim of the present work was the BSG valorization by its use in the formulation of a fiber-enriched fresh egg pasta. To improve pasta structure, the addition of egg white powder (EWP) was also evaluated. In order to simultaneously study the effect of the two considered factors (BSG and EWP amount) and to model pasta quality characteristics, an inscribed Central Composite Design was developed, applying the Response Surface Methodology for data elaboration. Finally, the obtained models were used to calculate an optimized formulation by means of the desirability function.

2. Materials and methods

2.1. Brewer's spent grain preparation

Brewer's spent grains (25 kg) were kindly supplied by Birrifico Lambrate S.r.l. (Milan, Italy) and stored at −18 °C until drying. The drying process was carried out on 2.1 kg aliquots in a vacuum oven (1325 Pa) at 60 °C for 48 h, in order to reach a moisture content lower than 3 g/100 g (2.82 ± 0.02 g/100 g in our sample). All the dried aliquots were then mixed and milled using first a disk miller (MLI 204, Uzwil, Switzerland) and then a Thermomix 31 (Vorwerk Contempora S.r.l., Milan, Italy), in order to achieve a particle size < 500 μm. Milled BSG were stored at 4 °C in vacuum packages until the use in pasta production.

2.2. Fresh egg pasta production

Fiber-enriched fresh egg pasta was produced using BSG prepared as reported in §2.1, durum wheat semolina (F.lli De Cecco di Filippo Fara San Martino S.p.A., Fara San Martino, Italy), soft wheat flour (Barilla G. e R. F.lli S.p.A., Parma, Italy), liquid pasteurized whole egg (Eurovo S.r.l., Occhiobello, Italy), egg white powder (Eurovo S.p.A., Occhiobello, Italy) and commercial natural spring water. Pasta samples were formulated with semolina and flour in a 1:1 ratio, keeping constant both the dough theoretical moisture content (about 36 g/100 g based on analytical moisture content of ingredients) and the liquid whole egg amount (20 g/100 g).

In addition to the samples of fiber-enriched pasta, one standard sample (STD) reflecting the average composition of commercial fresh egg pasta, without addition of BSG nor EWP, was prepared in duplicate (STD_a and STD_b). Liquid whole egg content was maintained at 20 g/100 g, whereas pasta theoretical moisture was decreased to 34 g/100 g in order to have a proper dough.

All pasta samples (1.5 kg each) were produced as reported in Alamprese, Casiraghi, and Rossi (2009). Briefly, sheets for *lasagna* (15 × 25 cm) were obtained using an automatic equipment for artisanal pasta production (P.Nuova, La Monferrina, Moncalieri, Italy). After 5 min mixing of the dried ingredients, the liquid ones were added and mixed for approximately 15 min. The crumbly dough was kneaded by rolling it at the minimum gap, and then structured by four passages between the rollers at the maximum setting. Finally, pasta was shaped into sheets approximately 1 mm thick and immediately subjected to analyses, keeping sheets in airtight polystyrene containers to avoid moisture loss.

2.3. Analytical determinations

Ingredient dry matter was determined according to official methods: AACC 44-15A (2000) for flour, semolina, and BSG; AOAC 925.30 (1995) for pasteurized whole egg and EWP. Soluble, insoluble, and total fiber content of BSG and semolina-flour mixture (1:1 ratio) was measured by using the total dietary fiber assay kit (K-TDFR) by Megazyme (Megazyme International Ireland, Bray, Ireland), based on the official method AOAC 991.43 (1995).

Each pasta sample was cooked for 3 min under standard conditions, maintaining a fixed pasta/water ratio of 1/10 (w/v) (Alamprese, Iametti, Rossi, & Bergonzi, 2005b). Raw and cooked pasta sheets were analyzed as previously reported (Alamprese, Casiraghi, Primavesi, Rossi, & Hidalgo, 2005a; Alamprese et al., 2005b) for moisture ($n = 2$; only on raw pasta), thickness ($n = 3$), mechanical properties ($n = 9$), and cooking behavior ($n = 3$) in terms of weight increase and matter loss. In particular, moisture content of raw pasta was determined by a gravimetric method, drying pasta for 24 h in an oven at 105 °C (DM, 1967). Thickness was measured using a calliper. Mechanical properties were measured by means of tensile tests performed using an Instron Universal Testing Machine 3365 (Instron Division of ITW Test and Measurement Italia S.r.l., Trezzano sul Naviglio, Italy) equipped with a 100 N load cell. Analyses were carried out on dumbbell-shaped samples at room temperature, with a constant cross-head speed of 20 mm/min. Pasta weight increase due to cooking was determined weighing pasta sheets before and after cooking. Matter loss during