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Effect of infrared finishing process parameters on physical, mechanical, and sensory properties of par-fried, infrared-finished gluten-free donuts

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ABSTRACT

Infrared radiation (IR) can simulate the heat flux created during the frying process, yielding products with fried-like textures but lower fat content. The objective of this study was to determine the process parameters needed to produce partially-fried, infrared-finished gluten-free (GF) donuts having similar instrumental and sensorial properties to fully-fried wheat and GF donuts but lower fat content. Eight different IR oven parameter settings were tested. All GF donuts had significantly lower ($p \leqslant 0.05$) fat content (23.7–28.2%) than the wheat control (33.7%). Several IR oven parameters yielded donuts that were instrumentally similar to the wheat and GF controls. All IR-finished GF donuts received significantly lower overall acceptance scores (3.81–3.44) than the wheat control (6.94), although they had similar sensory scores to the GF control (4.54). Infrared radiation may be used to finish-fry partially-fried GF donuts to produce donuts significantly lower in fat, yet instrumentally and sensorially similar to fully-fried GF donuts.

1. Introduction

Fried foods are enjoyed worldwide for their palatable texture and taste (Guallar-Castillón et al., 2007). Americans in particular consume large amounts of fried food, whether it is with a meal, such as chicken nuggets, French fries, and other fast-food products, or for a snack, such as potato chips. However, fried foods are generally high in fat and saturated fat, and are energy dense rather than nutrient dense. The rising prevalence of overweight and obesity in America is often attributed to the increased consumption of fast foods and fried foods (Nawar, 1998). With 66% of the American population considered overweight and 50% of those who are overweight considered obese (National Center for Health Statistics, 2006), obesity-related diseases have become a major health concern (Nicklas et al., 2001). Rising health concerns have caused many consumers to become more health conscious, resulting in an increased demand for foods with the same texture and taste of fried foods but with both lower calorie and fat content.

It is important to understand how heat and mass are transferred during frying to develop a method to lower fat content in fried foods, particularly if frying is partially or completely replaced with another heating method. Frying is a common process that produces foods with a crisp, crunchy crust and a soft interior. These textural attributes are largely due to the heating profile of foods during frying. After a food is placed into a deep fryer, there is a rapid increase in heat flux to a peak of about 30,000 W/m^2, then a gradual decrease in heat flux during subsequent cooking. As moisture on the surface of the food vaporizes and evaporates during cooking, the surface dries, resulting in crust formation. This crust continues to dry and thicken during the cooking process (Farkas and Hubbard, 2000). Because the structure of the crust is porous, oil is able to enter the food during and after frying, resulting in an increased fat content (Mellema, 2003).

Infrared (IR) heating has mainly been used for pasteurization, baking, thawing, and drying (Sakai and Hanzawa, 1994; Krishnamurthy et al., 2008), and has not been extensively studied as an alternative frying method. However, IR heating is able to provide a high heat flux that is easily controllable, allowing duplication of the heat flux profile found in frying. Lloyd (2003) developed a process that was able to reproduce the heat flux of frying using IR heating. French fries that were partially- (par-) fried and finished using the IR process had significantly lower fat content than fully-fried French fries: 13.0% versus 19.2%, respectively, although the instrumental and sensorial properties of the par-fried, IR finished fries were comparable to those of the fully-fried French fries (Lloyd, 2003). This IR-finishing process was also able to produce wheat donuts with comparable instrumental and sensorial properties to fully-fried wheat donuts. The par-fried, IR-finished wheat donuts also had significantly lower fat content than fully-fried wheat donuts: 25.6–30.6% versus 33.7%, respectively (Melito and Farkas, 2012).

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Food allergies and intolerances are a growing health concern in many developed countries. Gluten intolerance, which affects about 1% of the American population, is the inability to digest the gluten proteins found in wheat, as well as similar proteins found in barley, rye, and possibly oats. Prolonged consumption of these proteins by individuals with gluten intolerance results in gradual deterioration of the intestinal villi, causing malabsorption of nutrients and other health problems (Schober et al., 2003). Wheat allergy also involves sensitivity to wheat proteins, although the response to the consumption of these proteins differs from that of gluten intolerance. When an individual with a wheat allergy consumes wheat, an IgE-mediated response causes a histamine release, resulting in a variety of symptoms such as hives, nausea, GI distress, and anaphylaxis (Hischenhuber et al., 2006).

Current treatment of wheat allergy and gluten intolerance is a lifelong avoidance of wheat and wheat-containing products. In addition, gluten-intolerant individuals must also avoid gluten-containing products (Hischenhuber et al., 2006). The dietary requirements of these individuals has resulted in increased demand for commercial wheat- and gluten-free (GF) products. Although there are some GF analogs to commonly consumed products, such as cereals, bread, and cookies, product acceptability is variable and product taste and texture is usually not like that of the original wheat-based products.

There has been considerable study of formulation of GF breads to improve mechanical and textural attributes, but little research is available on other GF products, particularly fried products such as deep-fried doughs or breaded foods. However, GF flours have been found to significantly lower oil uptake during frying due to differences in the flour proteins (Mohamed et al., 1998; Altunakar et al., 2004; Shih et al., 2004). Several studies have commented on the potential of using GF flours in fried doughs or battered, fried products to produce foods with a lower fat content (Mohamed et al., 1998; Shih et al., 2001; Shih and Daigle, 2002; Shih et al., 2005). Incorporation of hydrocolloids into fried products as an ingredient or coating has also yielded lower fat content product (Shih and Daigle, 2002; García et al., 2004; Shih et al., 2005). Hydrocolloids, used in GF products to improve structure and texture, form an oil barrier during frying, resulting in decreased oil uptake. The mechanism of the oil barrier involves either physically blocking oil from entering the food during cooking or decreasing the surface hydrophobicity (Annapure et al., 1999; García et al., 2004).

Infrared heating has been successfully used to lower fat content while providing a fried-like texture and taste in both potatoes and wheat donuts (Lloyd, 2003; Melito and Farkas, 2012). It was hypothesized that using IR to finish-fry GF donuts would produce GF donuts with similar instrumental and sensorial properties to fully-fried GF donuts. In addition, it may be possible to produce par-fried, IR-finished GF donuts that have comparable instrumental and sensorial properties to fully-fried wheat donuts. The objective of this study was to determine the combination of par-frying and infrared parameters that produce the highest quality GF donut, as determined by instrumental and sensorial analysis, in comparison to both fully-fried GF donuts and fully-fried wheat donuts.

2. Materials and methods

2.1. Donut preparation

Wheat and GF donuts were formulated (Table 1) using an adaptation of a recipe from Sultan (1969). The recipe was adapted for a GF flour formulation by decreasing the amount of vanilla to 1.57 g, increasing the total amount of flour (a combination of commercial GF flour, rice flour, and pregelatinized rice flour) to 350 g, and adding 3.52 g of xanthan gum to the formulation as a gluten replacer.

Table 1
Formulation for wheat and GF donuts.

Ingredient	Weight (g)	% weight[a] (total flour basis) (%)	% weight (total weight basis) (%)
Wheat donut formulation			
Flour	302.4	100	49.7
Water	113.4	38	18.6
Shortening	56.7	19	9.31
Egg	37.8	13	6.21
Water for yeast	37.8	13	6.21
Sugar	18.9	6.3	3.10
Nonfat dry milk powder	18.9	6.3	3.10
Yeast	9.00	3.0	1.48
Salt	4.72	1.6	0.775
Vanilla extract	4.72	1.6	0.775
Baking powder	4.72	1.6	0.775
GF donut formulation			
Commercial GF flour[b]	175.0	50	27
Rice flour	164.5	47	25
Water	113.4	32	17
Shortening	56.70	16	8.6
Egg	37.80	11	5.8
Warm water	37.80	11	5.8
Sugar	18.90	5.4	2.9
Nonfat dry milk powder	18.90	5.4	2.9
PGRF	10.50	3.0	1.6
Yeast	9.00	2.6	1.4
Salt	4.72	1.3	0.72
Baking powder	4.72	1.3	0.72
Xanthan gum	3.52	1.0	0.54
Vanilla extract	1.57	0.45	0.24

[a] Total flour weight is the sum of the weights of the commercial GF flour, the rice flour, and the pregelatinized rice flour.
[b] Although the exact amounts of the flours used in this baking mix were unavailable, the flours used in this mix were, by weight order, garbanzo bean flour, potato starch, tapioca flour, sorghum flour, and fava flour.

Pregelatinized rice flour was obtained from Sage Foods (Los Angeles, CA). Xanthan gum and methylcellulose were obtained from TIC Gums (Belcamp, MD). All other ingredients were purchased from a local supermarket (Harris Teeter, Raleigh, NC). The GF flour formulation included rice flour, garbanzo bean flour, potato starch, tapioca flour, sorghum flour, and fava flour, as well as pregelatinized rice flour used as a thickener (Table 1).

Preliminary work was performed to determine the amounts of GF flours needed to replace the wheat flour in the original recipe (Melito and Farkas, 2013). Blending the commercial GF flour with rice flour reduced grittiness normally associated with products made using only rice flour while mitigating the beany flavor of the commercial GF flour. Addition of pregelatinized rice flour and xanthan gum to the GF flour blend improved the overall physical and mechanical properties of the donuts. The methylcellulose coating also improved physical and mechanical properties of the GF donuts, although it did not have a significant impact on fat content (Melito and Farkas, 2013). The same formulation was used for all GF donuts.

The donut dough was prepared by hand-mixing the sugar, salt, nonfat dry milk powder, and shortening in a mixing bowl. Yeast and the water for the yeast (35 °C) were mixed together separately and allowed to sit for 5 min. Egg was added to the shortening and combined with the dry ingredients, followed by the water. Vanilla extract was then added and blended in. In a separate beaker, the GF flours (Table 1) and xanthan gum were combined with the baking powder, then blended into the other ingredients until moistened. Lastly, the yeast mixture was added. The mixture was kneaded to form a dough, covered lightly in rice flour to prevent sticking, and rolled out on waxed paper to a thickness of 9 mm. The dough was then cut into squares approximately 50 mm on each side. Approximately 1 g of methylcellulose wash, made by mixing 0.50 g methylcellulose with 50.0 g water using an immersion blen-