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Physicochemical properties and sensory attributes of resistant starch-supplemented granola bars and cereals

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ABSTRACT

The purpose of this study was to evaluate the effects of resistant starch (RS) on physicochemical and sensory properties of cereal-based food products. RS granola bars and cereals containing two levels of RS (10 g/100 g and 15 g/100 g) were compared to isocaloric (0 g RS/100 g) control granola products. Texture, color, proximate composition, caloric content, water activity, RS, and soluble starch (SS) were measured. Sensory acceptability was evaluated using a 9-point hedonic scale. Attributes (color, sweetness, moistness, crunchiness, stickiness, chewiness) of the RS bar, control bar, and two commercial bars were also assessed with a "just about right" (JAR) sensory method. High RS bars contained 6 g/100 g protein, 15 g/100 g moisture, and 18 g/100 g lipid. RS levels increased from 14 to 16 g/serving after 4 weeks of storage, supporting published research that RS increases with storage due to retrogradation of amylose chains. Soluble starch concentrations were not changed during storage. Color became lighter as the level of RS increased. Consumer acceptability results indicated that the granola bars/cereals were acceptable. The RS granola bars differed significantly in stickiness ($p < 0.0001$), and chewiness ($p = 0.0063$) compared to the control and 2 commercial granola bars. Incorporation of high levels of RS in food systems is feasible without compromising product acceptability.

1. Introduction

Starch, a major component of the human diet (Lehman & Robin, 2007), is widely used in processed foods (Brown, 2004). Processing conditions may change the structure of granular starch to nongranular forms (Murphy, Douglass & Birkett, 2008). Starch structure affects the digestibility of the starch. Therefore, not all starch forms are hydrolyzed equally by digestive enzymes (Patil, 2004; Tapsell, 2004). Resistant starch (RS) was first recognized in the 1980s when it was found to be resistant to enzymatic hydrolysis (Englyst, Kingman, & Cummings, 1992), and it has been defined as 'the sum of starch and products of starch degradation not absorbed in the small intestine of healthy individuals' (Asp, 1992). There are four major types of RS. RS1 is the physically entrapped or inaccessible RS found in the cell wall of whole or partially milled grains and seeds as well as legumes. RS2 is the native resistant ungelatinized granules found in raw potatoes, green bananas, and high amylose corn starches. RS3 is the retrograded crystalline starch formed during conventional food processing methods in products such as cooked and cooled potatoes and pasta, bread, ready-to-eat cereals, and retrograded high amylose corn starches. RS4 is chemically modified starch cross-linked with chemical agents (Brown, 2004; Patil, 2004; Sajilata, Singhal, & Kulkarni, 2006; Topping, Fukushima, & Bird, 2003).

In recent years, RS has been classified as a functional fiber. RS is not digested in the small intestine and, therefore, has many of the physiological health benefits associated with dietary fiber (Charalampopoulos, Wang, Pandiella, & Webb, 2002). Dietary fibers, including RS, promote beneficial physiological effects including laxation, blood cholesterol attenuation and blood glucose attenuation (Patil, 2004). The benefits of RS on glycemic control have been shown in healthy, overweight, and diabetic subjects (Brown, 2004). Feeding of a liquid beverage containing 24 g/d uncooked RS3 (retrograded starch) to overweight individuals for 21 d resulted in lower blood cholesterol and glucose levels compared to feeding regular corn starch (Park, Kang, Chang, & Kim, 2004). Prior consumption of uncooked RS2 (60 g/d for 24 h) resulted in lowered postprandial plasma glucose and insulin levels in healthy subjects the following day after a meal tolerance test (Robertson, Currie, Morgan, Jewell, & Frayn, 2003).

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The recommended dietary fiber intake is 25 g/d and 38 g/d for women and men, respectively; however, most Americans consume ≤ 14 g/d of dietary fiber, well below the recommended intakes (Institute of Medicine, 2005). Increasing the dietary fiber content of foods, such as granola bars and cereals, by supplementation with RS is one approach to increasing dietary fiber intake. According to Kendall, Emam, Agustin, and Jenkins (2004), RS doses of 20–30 g/d are needed to observe physiological effects of RS consumption. This level of consumption is 3–4 times higher than the actual levels of RS consumption in Western countries, which are estimated to be 5–10 g/d RS; estimated RS intake in the U.S. is 3–8 g/d. Most foods have RS contents of 3 g or less per serving (Murphy et al., 2008). These estimates provide useful information for food scientists and nutritionists when developing food products supplemented with RS and evaluating the potential health benefits of these products. Consumers value convenience and healthy alternatives such as granola bars that are low-calorie, low-fat, and high-fiber. According to Mintel International Group Ltd, cereal bars sales were $1.4 billion in 2007, an increase of 43 g/100 g from 2002 (Teen, 2008).

Resistant starch has been shown to improve textural and organoleptic characteristics, along with increasing the amount of dietary fiber in some food products (Kendall et al., 2004). Resistant starch acts as a prebiotic component by promoting the growth and activity of probiotic bacteria and can interact with other prebiotic dietary fibers such as β-glucans (Brown, 2004; Goldring, 2004; Topping et al., 2003). RS levels in foods have been shown to increase during storage due to retrogradation and amylose chain crystallization (Kumari, Urooj, & Prasad, 2007; Namratha, Asna, & Prasad, 2002; Niba, 2002, 2003a; Sajilata et al., 2006).

Formation of RS in foods is determined by the starch botanical source, extent of processing, and storage conditions (Namratha et al., 2002; Niba, 2003a, 2003b). Most physiological studies of the health benefits of RS have been conducted by adding RS as uncooked powders to beverages and jellies at levels of 24–60 g RS/d (Park et al., 2004; Robertson, Bickerton, Dennis, Vidal, & Frayn, 2005). However, the problem with this approach is that RS would not normally be used in un-heated foods. Thus, the purpose of this study was to determine effects of formulation and storage time on the physicochemical properties, RS conversions, and consumer acceptability of baked cereal foods (granola bar, granola cereal) with RS supplemented at levels reported for health significance.

2. Materials and methods

2.1. Product preparation and sample preparation for analyses

A commercially available RS2 was used (Hi-Maize® 260, National Starch Food Innovation, Bridgewater, NJ, USA) that contained 60 g RS/100 g total starch based on supplier information based on total dietary fiber analysis. Commercially available waxy corn starch (Amioca®, National Starch Food Innovation, Bridgewater, NJ, USA), used in the formulation of the isocaloric (control) granola bars and granola cereals contained 40 g readily digestible starch/100 g total starch.

Granola bars and cereals were designed to provide 0, 10, and 15 g RS/100 g serving using the formulations described in Table 1. In addition to the RS2 and waxy starch, the granola bars and cereals ingredients were: a) oats (Quaker Oats, Old fashion, 100% whole grain, Chicago, Il, USA), b) dried flakes of sweetened coconut (Kroger, Cincinnati, OH, USA), c) sliced almonds (Kroger, Cincinnati, OH, USA), d) canola oil (Crisco®, Orrville, OH, USA), e) clover honey (Kroger, Cincinnati, OH, USA), f) egg whites (Kroger, Cincinnati, OH, USA), and g) baking soda (Arm & Hammer, Princeton, NJ, USA).

Products were prepared by mixing dry ingredients (oats, RS2 at 10 and 15 g RS supplemented bars and cereals) or waxy corn starch (control bars and cereals), coconut, almonds, and baking powder) with liquid ingredients (clover honey, canola oil, and egg whites). Granola cereals contained the same ingredients except egg whites, gum arabic, and baking powder and were prepared similarly. Products were baked in a conventional oven at 163 °C for 35 min until golden brown and cooled to room temperature. Granola bars and cereals were packaged in individual portions (Table 1) sufficient for analysis in metalized multilayered flexible pouches (Mylar®MC2, DuPont Teijin Films US, Wilmington, DE, USA) and stored at 20 °C for 4 weeks. Two replicate batches of each treatment were made, and two product packages from each batch per treatment were analyzed at 0, 7, 14, and 28 d.

Table 1
Resistant starch (15 g RS/100 g and 10 g RS/100 g RS) and control granola bar formulations.[a]

Ingredients	Weight (g) per Bar (15 g RS)	Weight (g) per Bar (10 g RS)	Weight (g) per Bar (Control)
Oats	22.5	22.5	22.5
RS2: Hi Maize®	33.5	25.0	0.0
Waxy Corn Starch Amioca®	0.0	0.0	13.4
Shredded Coconut	4.4	4.4	4.4
Almonds	5.6	5.6	5.6
Baking Soda	0.6	0.6	0.6
Honey	20.8	20.8	20.8
Canola Oil	14.5	14.5	14.5
Egg Whites	2.8	2.8	2.8
Vanilla Extract	0.3	0.3	0.3
Vanilla Imitation	0.3	0.3	0.3
TIC gum Arabic	1.3	1.3	1.3
Total	*106.5*	*98.1*	*86.5*

[a] Eight granola bars per batch. Cereals contained the same ingredients as granola bars except egg whites, TIC gum Arabic, and baking soda. Honey and oil were increased to 31.2 g and 21.8 g per bar, respectively to aid in dispersion of starch.

2.2. Extraction and determination of resistant starch (RS) and soluble starch (SS)

Granola cereals or bars were ground (Black and Decker® Smart Grind Coffee Grinder, Towson, MD, USA) for approximately 60 s to pass through a 1.0 mm sieve, freeze dried (Virtis Freeze Dryer, SP Industries Inc., Gardiner, NY, USA) for 48 h, and stored in desiccators until analyzed. The assay was performed using a commercially available kit for RS determination (Megazyme International Ireland Ltd., Bray, Co. Wicklow, Ireland). Freeze-dried ground sample material (100 mg) and sodium maleate buffer (pH 6.0) containing pancreatic α-amylase and amyloglucosidase (AMG) (3 U/ml) were combined. Sample was mixed and incubated in a shaking water bath for 16 h at 37 °C. The non-resistant starch was solubilized and hydrolyzed to glucose by two enzymes. The reaction was stopped by adding 50 g/100 g ethanol (EtOH) solution. The tube was mixed for 60 s and centrifuged at 1000 × g for 10 min. The pellets were used for RS determination and the supernatants were decanted and used for SS determination. RS and SS concentrations were determined using procedures described by McCleary and Monaghan (2002), based on the Association of Official Analytical Chemists (AOAC) method 2002.02.

2.3. Proximate analysis, caloric content, and water activity

Control and RS-supplemented granola bars and cereals ground as previously described and analyzed for crude fat, ash, moisture, and crude protein (AOAC official methods of analysis sections 960.39, 923.03 and modified sections 950.46 and 981.10 respectively) (AOAC, 1984). Carbohydrate content was determined by difference. Caloric content (kcal/100 g) of bars and cereals was