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Gluten-free breadmaking: Improving nutritional and bioactive compounds

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ABSTRACT

This review focuses on the contemporary approaches that are used to increase nutrient and bioactive compound contents of gluten-free bread (GFB), and highlights the use of nutrient-dense alternative raw materials, nutritional and functional ingredients, and their combinations. Few studies address micronutrient fortification in GFB, and only one study has addressed the performance of *in vitro* trials to examine bioaccessibility. Some studies have demonstrated the potential use of nutrient-dense raw materials, dietary fiber enrichment and technological processes in decreasing the GFB glycemic response, which is evaluated through *in vivo* trials or by using the *in vitro*-predicted glycemic response method. The reviewed studies have shown promising approaches to overcoming both the technological and nutritional challenges involved in GFB development. However, further studies on the improvement or development of new nutrient-dense GFB and their evaluation using digestibility, bioaccessibility, and bioavailability trials are required to understand or improve their efficacy as vehicles of micronutrients and bioactive compounds. In addition, short- and long-term controlled clinical trials are needed to evaluate their potential health benefits. Furthermore, efforts to apply some of this promising research to commercial products should be made to make GFB with good technological, sensory and nutritional properties available to consumers with gluten-related disorders.

1. Introduction

The once small GF food market has experienced increased growth in recent years and has become a trend in the food sector. This growth has occurred primarily because of a GF craze that has made consumers avoid gluten because they believe that GF products are a “healthier” option and that a GF diet is an effective way to lose weight, although there is no scientific evidence to support these beliefs (Brouns et al., 2013; Pszczola, 2012). For individuals with CD, dermatitis herpetiformis, gluten ataxia, wheat allergies and gluten sensitivity, the GF food market segment is important for assisting in their adherence to a strict GF diet (Sapone et al., 2012). Despite the growth of the GF market, individuals with CD still have trouble finding GF products because of high prices, limited variety and availability and poor sensory properties. These factors are responsible for hampering adherence to the GF diet and for general dissatisfaction (do Nascimento et al., 2014).

Despite the considerable advances made in understanding and improving GF systems by evaluating different ingredients, additives, and technologies over the past two decades, the development of GF products remains a technological challenge due to the role of gluten in various grain-based products. The technological challenge increases according to the dependency of products' properties on gluten, which is considerable in bread and pasta making (Capriles et al., 2015). Bread is the most studied among all GF products. However, a GFB with a good sensory aspect remains the most desired product by individuals with CD (do Nascimento et al., 2014).

A range of GFB formulations have been developed by using rice and maize flours, which are often combined with maize, potato, or cassava starches as base flours because they are widely available, inexpensive ingredients that are bland in taste and flavor. However, these flours and starches have minimal structure-building potential and, thus, are frequently used along with proteins and hydrocolloid

Abbreviations: CD, Celiac disease; DF, Dietary fiber; fwb, flour weight basis; GF, Gluten-free; GFB, Gluten-free bread; GI, Glycemic index; GL, Glycemic load; GR, Glycemic response; HI, Hydrolysis index; HPMC, Hydroxypropylmethylcellulose; ITFs, Inulin-type fructans; RS, Resistant starch; RSM, Response surface methodology.

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binding agents and with other additives to improve GFB physical properties, acceptance and shelf-life (Capriles and Arêas, 2014). These GF flours and starches are not generally enriched or fortified, and neither are the resulting GF products, in the same way as their wheat-based counterparts. Therefore, GF products may lead to nutritional deficiencies in micronutrients, protein and DF (do Nascimento et al., 2013; Kinsey et al., 2008; Thompson, 2000). Thus, enhancing the nutritional quality of GF products remains an important task for research and development, which is a concomitant challenge towards the improvement of technological and sensory properties.

The development of GFB is still a challenge because no single raw material, ingredient, or additive can currently replace gluten fully. Nevertheless, great research advances have been made in this field. Several recent studies have used food science tools to improve the technological and sensory qualities of GFB, together with the nutritional value (Capriles and Arêas, 2014). It is not the objective of this review to list all of these advances.

The primary focus of this review is to discuss the current approaches used to improve the nutritional and bioactive compounds of GFB. This review concentrates on contemporary GFB research (as published since 2005), with particular focus on raw materials and ingredients that improve the nutritional properties of GFB, especially the sensory-accepted ones.

2. Nutrient-dense alternative raw materials

Research has shown that some nutrient-dense alternative raw materials that are derived from non-gluten cereals, pseudocereals, legumes, nuts, seeds and fruit- and vegetable-based ingredients can be used to develop GFB with good physical and sensory properties, along with enhanced nutritional composition (Capriles and Arêas, 2014).

Despite their nutritional benefits, the use of whole grain flours and other alternative raw materials presents certain technological limitations because these flours can change the appearance, color, texture, aroma, and taste of GFB, which can easily impair consumer acceptability. Consequently, nutrient-dense alternative raw materials have frequently been used in combination with conventional GF flours and starches (rice flour and starch, maize flour and starch, and potato, cassava and wheat starches) in composite GFB formulations. However, some good-quality single formulations have also been developed.

Various approaches have been applied to develop and improve the physical properties of GFB based on single formulations made with whole grain maize, oat, and rice flours. The inclusion of oats in GF products has been controversial for years because although this ingredient can improve a product's quality and diversify the GF diet, it may contain gluten. Therefore, the allowance of pure oat in GF products is determined by each nation's labeling regulations.

Interesting results were obtained by Brites et al. (2010), who developed a GF “broa” bread formulation based on whole yellow maize flour, which presents no significant differences compared with the sensory characteristics of maize- and wheat-based traditional broa in a paired preference test. Kim and Yokoyama (2011) developed a formulation of all-oat breads with the addition of 5% HPMC (fwb). Oat-based GF bread contains 1% β-glucan and has received sensory scores ranging from 4.3 to 5.1 on a 7-point hedonic scale, with no acceptability difference compared with that of whole wheat bread. Interesting results were recently reported by Cornejo et al. (2015), who investigated the effects of different germination times (0, 12, 24 and 48 h) of brown rice flour on the nutritional quality of brown rice flour-based GFB. The results show that germination for 48 h enhances the nutritional quality of GFB by increasing the protein, lipid and bioactive compound contents (c-aminobutyric acid and polyphenols), increasing the antioxidant activity and reducing the phytic acid content and *in vitro* enzymatic hydrolysis of starch.

Studies of composite GFB formulations have shown promising results regarding the physical properties of GF dough and bread when using up to 70% sorghum flour in combination with corn, potato, rice, or cassava starches (Onyango et al., 2011; Schober et al., 2005).

Some researchers have investigated the feasibility of using pseudocereals in GF breadmaking. Alvarez-Jubete et al. (2009a, 2009b, 2010a, 2010b) replaced potato starch with amaranth, buckwheat, or quinoa flour in a control formulation with 50% rice flour and 50% potato starch. These pseudocereals increased the protein, fiber, calcium, iron, vitamin E, and polyphenol contents and the *in vitro* antioxidant activity of GFB. The GFBs containing pseudocereals presented a softer crumb texture and darker crust and crumb colors. However, no significant differences were observed between the acceptability scores of the pseudocereal breads and the control GFB, which resulted in medium acceptability (scores ranging between approximately 2 and 3 on a 6-cm scale) (Alvarez-Jubete et al., 2010c).

In the production of acceptable GFB, researchers have reported good results with rice-based composite flour that was made of up to 50% buckwheat (Alvarez-Jubete et al., 2010c; Torbica et al., 2010) and with corn starch-based flour composed of up to 40% buckwheat flour (Wronkowska et al., 2010). These levels increased the nutrition and antioxidant compounds and the antioxidant capacity of GFB.

Marciniak-Lukasiak and Skrzypacz (2008) reported good results when adding 10% amaranth flour to the total GFB mass, which increased the nutrient contents and resulted in approximately 50% consumer acceptability. Lemos et al. (2012) also observed the best results in a cheese bread with a mixture containing 10% amaranth flour, which increased the DF and iron contents and maintained the same level of acceptance as that of the control formulation (for a score of 6.8 on a 9-point hedonic scale). Interesting results were also found by de la Barca et al. (2010), who prepared 100% amaranth GFB with different ratios of popped and raw amaranth flour. The best formulation contained 60% popped amaranth flour and 40% raw amaranth flour, which produced breads with a homogeneous crumb and a higher volume.

Legume flours have also been investigated in GFB formulations, and promising technological and sensory results have been achieved in composite formulations with soy, chickpea, carob germ, and vinal (Minarro et al., 2012). Further research should evaluate the acceptability and compositions of these breads. Tsatsaragkou et al. (2012) observed that the addition of 15% carob germ to a rice-based GFB formulation resulted in a product with good physical properties that was enriched with DF (6.1%) and protein (8.4%) and was a source of some minerals. Interesting results were reported by Shin et al. (2013), who developed a 100% soybean GFB. Bread made with heat-treated soy flour (steaming or roasting) was perceived to have a less beany aroma and taste than a GFB made with non-heat-treated flour (germination).

Other alternative flours have been investigated, and promising results have been achieved with seeds and nuts. Costantini et al. (2014) replaced common and tartary buckwheat flour with 10% whole chia flour and observed an improvement in the protein, lipids, DF, ash, α-linolenic acid, and phenolic compound contents, and the antioxidant capacity of the formulations. Steffolani et al. (2014) observed that the replacement of rice flour with 15% whole chia flour or 15% chia seeds diminished the GFB physical properties but did not reduce the medium overall acceptability (for scores of approximately 5, indicating neither like nor dislike, on a 9-point hedonic scale). Demirkesen et al. (2010, 2013) studied the