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Gluten-free pastas: ingredients and processing for technological and nutritional quality improvement

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Abstract

The challenge in the production of gluten-free pasta is in obtaining the technological and nutritional quality already achieved for wheat-based pasta. This review covered the main ingredients and processes used to produce gluten-free pasta, and points to future perspectives for this product. It was found that the ingredients used for technological improvement aimed to reproduce a network with polymers, of the protein type (mainly eggs, pseudo-cereals and legumes), starches (flours and/or isolated starches) and hydrocolloids (gums) for structuring gluten-free pastas. The use of regional raw materials stands out as innovative ingredients that add value and health and at the same time, promote sustainability. For nutritional improvement, those with a high content of proteins and fibers stand out, but studies on enrichment with micronutrients are lacking. For processing, studies are using equipment, mixing times and drying processes similar to wheat-based pasta, with few innovations, except those obtained by thermoplastic extrusion. In conclusion, research with gluten-free pasta needs greater investments to move towards the development of differentiated formulations and processing, as with wheat-based pastas, which has evolved over centuries.

Keywords: wheatless pasta; quality; nutrients; processing; healthiness; sustainability.

Practical Application: This review presents the state-of-art of the gluten-free pasta studies, highlighting the needs for research and development for technological and nutritional improvement of these products, and proposing some guidelines for the selection of its ingredients and processes.

1 Introduction

Gluten-free pasta (GFP) has been produced to meet the demand of individuals who cannot consume conventional pasta due to an intolerance or allergy to wheat and similar cereals, such as rye and barley, which should be permanently excluded from the diet (Lee & Newman, 2003; Tonutti & Bizzaro, 2014). The number of consumers of GFP has increased due to the accessibility of information about nutrition and health, and the access to diagnostic methods for gluten-related disorders, including celiac syndrome (Nascimento et al., 2014). However, there is still necessary enhancing the social awareness and information regarding the celiac disorders, and contribute to increasing the variety of gluten-free products in local markets (Taşkin & Savlak, 2021).

Many consumers report that GFPs are more brittle in cooking, or have an unattractive texture, flavor and color, factors related to several technological defects caused mainly by the lack of a gluten network. The GFP consumers also include those who choose not to eat wheat-based products due to the relationship between gluten intake and healthy eating (Heller, 2009). However, replacing the wheat flour with other cereals and/or tubers cannot provide health benefits to the GFP. For example, Missbach et al. (2015) found that the gluten-free products available on the Austrian market in 2015, including GFPs, showed less protein, minerals, and vitamins content when compared with its equivalent wheat-based version. The GFPs also present less dietary fiber, and a predominance of starchy carbohydrates in its composition.

Thus, the objective of this review is to present the state-of-the-art regarding the ingredients and processes to produce GFP with better technological and nutritional quality, covering the studies developed in the last five years, and to propose some recommendations for the ingredient selection.

2 Ingredients in gluten-free pasta

Different combinations of ingredients can be used to provide the effect of the gluten network in the structuring and shaping of GFP. Figure 1 shows a didactic division of these ingredients into structure-forming agents, technological improvers, and nutritional improvers, which will be the classification used in this review.

2.1 Structuring ingredients (structurants)

This is a category of ingredients that are used to form a three-dimensional network capable of maintaining the shape of the GFP during the drying process, and after cooking, and it includes different types of starch and proteins. Table 1 shows the different ingredients and processes for GFPs production.

Starch

Starch is a reserve polymer made up of glucose units, found in vegetable tissues in the form of water-insoluble granules, which has two types of polymers: amylose and amylopectin. In GFPs,

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Table 1. Formulations, manufacturing processes of gluten-free pastas (GFP) and technological and nutritional evaluated effects.

Pasta	Ingredients	Process for pasta production	Nutritional effects	Technological effects[a]	References
Dry, long, *spaghetti*	Rice flour; bean flour with low phytic acid and lectin free (BF); water. *Total samples*: 2 GFPs and a control (100% rice flour).	Mixing (5 min.) and hydration (50 mL of warm water for 100 g of dry ingredients); shaping (lamination in pasta machine); drying (30 °C, 12 min; after, 45 °C, 240 min)	BF ↑resistant starch content	BF ↑cooking time and water absorption capacity	Giuberti et al., 2015
N.S.	Chickpea flour; Green mussel powder (GMP); refined sunflower oil. *Total samples*: 5 GFP and a control (100% chickpea flour).	Mixing; shaping (pasta machine); drying (55 °C, 3-4 h)	GMP ↑antioxidant activity	GMP enhanced the protein matrix (observed by scanning electron microscope micrographs)	Vijaykrishnaraj et al., 2015
Dry, long, *spaghetti*	Rice flour (RF) and yellow pea flour; lentil flour; RF and chickpea flour; water. *Total samples*: 9 GFPs and a control (GFP, only RF).	Single-screw thermoplastic extrusion (70-100 °C, three different moisture content: 28%, 30%, and 32%); drying (40 °C, 4 h, until moisture content < 12%).	N.S.	GFPs had less firmness (2.73 to 4.94 N) than the control (12.12 N).	Bouasla et al., 2016
Dry, long, *spaghetti*	Combinations of sorghum flour (SF), rice flour (RF, corn flour (CF) and potato starch (PS); eggs; soybean oil; water. *Total samples*: 15 GFPs (simplex-lattice design).	Mixing of eggs with water and oil; hydration of dry ingredients (6 min); homemade method for shaping; drying (50 °C, 1 h; after, 60 °C, 30 min).	N.S.	GFP 40:20:40 (SF:RF:PS): ↑ volume, ↓ cooking time and cooking loss.	Ferreira et al., 2016
Dry, long, *spaghetti*	Faba bean flour; black gram flour (BGF); green-lentil flour; water. *Total samples*: 3 GFPs, and a commercial GFP (maize, millet, rice flours and cane sugar syrup).	Extrusion (single-screw pasta extruder); drying (55 °C, 12 h, until 11% humidity).	Leguminous flours contribute to ↑content of insoluble fibers	BGF ↓cooking loss.	Laleg et al., 2016
Dry, long, *spaghetti*	Rice flour; resistant starch type II (RS II); propylene glycol alginate, distilled monoglycerides; water. *Total samples*: 3 GFPs and a control (GFP, without RS II).	Cooking and mixing of ingredients (130 °C for 10 min (control) or 15 min (other GFPs), shaping (20 rpm, 30 to 34 °C, and vacuum); drying (50 °C and 76% RH, 12 h).	The production process conditions ↓RS II content.	GFP made with RS II: ↑ firmness than the control.	Foschia et al., 2017
Dry, long, *spaghetti*	Blue maize (BM); white maize (WM); water; unripe plantain; chickpea; carboxymethyl cellulose gum; water. *Total samples:* 6 GFPs.	Single-screw thermoplastic extrusion (< 50 °C); drying (45 °C, 16 h).	BM contributes to ↑dietary fiber, and resistant starch.	BM: ↓ hardness and chewiness, ↑darker color.	Camelo-Méndez et al., 2018
Fresh, long, *fettuccine*	Rice flour, maize flour, yellow passion fruit peel flour (YPPF), salt, oil, xanthan gum, eggs. *Total* samples: 2 GFPs and a control (GFP, without YPPF).	Mixture; shaping (pasta extruder).	YPPF ↑ash, and dietary fiber.	YPPF ↑ of cooking time, soluble solids loss, and water absorption.	Ribeiro et al., 2018
Dry, long *tagliatelle*	Corn flour; quinoa flour (QF); dry egg and dry egg white; zein protein; xanthan gum, locust bean gum; sunflower oil; water. *Total samples*: 8 GFPs and a control (without quinoa and zein).	Mixing; shaping (lamination in noodle machine); drying (60 °C, 60% RH).	N.S.	Zein and QF ↑adhesiveness and softness.	Sosa et al., 2019
Dry, long, N.S. format	Rice flour; lupine flour; whole egg; guar gum. *Total samples*: 20 GFPs and a control (100% rice flour) - 1 GFP was selected for nutritional evaluation.	Mixing; hydratation; extrusion; drying (60 °C, 4 h)	LF ↑ash, fat, protein, and fiber contents	LF ↑weight gain and loss of solids.	Albuja-Vaca et al., 2020
Dry, short, *maccheroni*	Buckwheat flour; teff flour (TF); chickpea flour (CF); xanthan gum (XG); water. *Total samples*: 15 GFPs.	Mixing (BF with boiling water); resting (24 h); addition of other ingredients; shaping in a pasta maker; drying (60 °C to 100 °C, 4 h).	TF and CF ↑protein content	N.S.	Güngormüşler et al., 2020
Fresh, long, *pappardelle*	Tiger nut flour and chickpea flour, fenugreek flour (FF), egg, water. *Total samples*: 4 GFPs and a control.	Mixing; kneading; resting; storage (20 min. in plastic bag, 4 °C); shaping.	FF ↓glycemic index, and ↑fiber content.	FF ↓cooking loss; water absorption index, and swelling index.	Llavata et al., 2020
Fresh, long, *spaguetti*	Cassava starch; corn flour, whole milk powder; salt; xanthan gum (XG); vegetable fat, whole fresh eggs. *Total samples*: 3 GFPs and a control (without XG)	Mixing; lamination; cutting.	N.E.	XG ↓cooking loss, ↑firmness, springiness, cohesiveness, and cutting force	Milde et al., 2020
Dry, short, *fusilli*	Rice flour, biofortified sweet potato flour (BSPF), hydrolyzed soy protein concentrate, sodium carboxymethyl cellulose gum, and monoglycerides. *Total samples*: 17 GFPs (without control) - 3 of these were selected for nutritional evaluation.	Mixing; resting; shaping (extrusion); drying (45 °C to 55 °C, ≤ 60 Relative Humidity, until moisture < 14%).	BSPF ↑β-carotene level, and total dietary fiber content.	Higher contents of HSPC associated with CMC ↑ the level of cracks; the HSPC addition also leaded to a darker color	Scarton et al., 2021
Dry, long, *spaguetti*	White maize flour, orange fleshed sweet potato flour.	Mixing; thermoplastic extrusion (twin-screw); drying (20 °C, overnight).	OFSP ↑ash, insoluble and soluble fiber, and antioxidant activity	High content of OFSP ↑cooking loss and ↓cookingtime and water absorption capacity	Baah et al., 2022

[a]↑ = increased; ↓ = decreased. N.S.: not specified; N.E.: not evaluated.

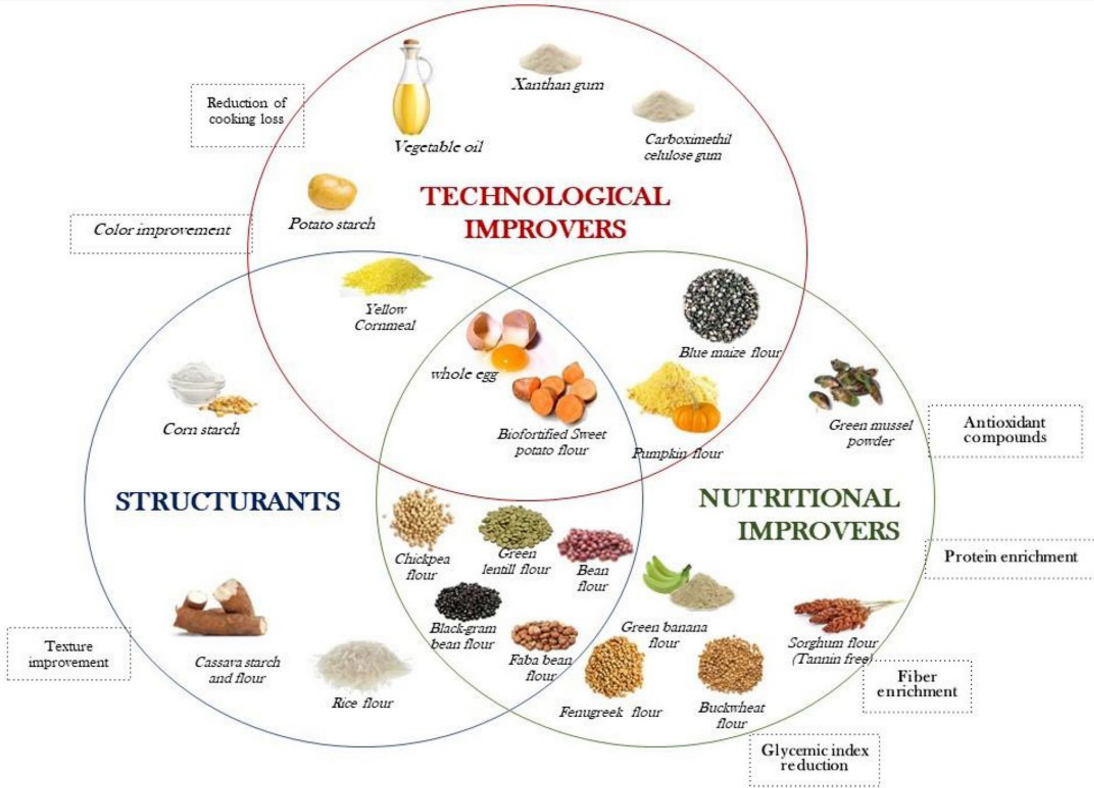

Figure 1. Classification of ingredients used for gluten-free pasta production.

flours from plant sources, such as cereals, pseudo cereals, roots, or tubers may be used as ingredients, as well as its isolated starches. The structure of GFPs is directly related to its gelatinized starch content (Abdel-Aal, 2009). During cooking, heat allows the amylose and amylopectin chains to interact with the water molecules through hydrogen bonds, causing swelling and the rupture of the granules and leading to the gelatinization process (Vaclavik & Christian, 2008). After cooling, the retrogradation process occurs, which is a structural reorganization of the starch and water releasement (Ross & Wrolstad, 2012).

The main starch sources for GFP are rice (Giuberti et al., 2015; Bouasla et al., 2016; Ferreira et al., 2016; Foschia et al., 2017; Albuja-Vaca et al., 2020; Scarton et al., 2021) and corn (Ferreira et al., 2016; Larrosa et al., 2015; Camelo-Méndez et al., 2018; Milde et al., 2020; Baah et al., 2022), as they are less expensive raw materials due to their market value and large-scale production.

Starches may exhibit different chemical organizations, amylose: amylopectin ratios, granule size, gelatinization temperatures and pasting characteristics. Therefore, the association between distinct sources of these polysaccharides may have a positive effect on the structuring of the GFP. Cereal starches, such as corn, for example, with 28 g and 72 g/100 g of amylose and amylopectin, respectively (Ross & Wrolstad, 2012), have a short texture, high viscosity, and a very rapid retrogradation after gelatinization, which causes excessive hardening and cracking in the GFP containing only these ingredients, making it difficult to consume after storage and reheating (Abdel-Aal, 2009).

To improve the quality of cereal based GFPs, root and tuber starches have been added, such as potato (Bastos et al., 2016), sweet potato (Marengo et al., 2018) and tiger nut (Llavata et al., 2019), as these form a translucent gel and with a long texture, with slow retrogradation during cooling, maintaining a soft texture in the GFP for a long time. There is also the use of gluten-free mixes for GFPs with the combination of flours and/or starches of many vegetable sources, as used by Ferreira et al. (2016), for example, blended sorghum flour, rice flour, maize starch and potato starch. However, it was observed that despite the potential of roots and tubers as a low-cost ingredient accessible worldwide, there are few current studies using these ingredients for GFPs production.

The modified starches can also be used for structuring the GFPs (Marti & Pagani, 2013). Starches obtained by physical process of modification, such as gelatinization, are the most used among the modified starches since they are considered Generally Recognized as Safe (GRAS), whereas chemically modified starches have limitations to be added in foods. The physical process of modification, such as gelatinization, are the most used among the modified starches, whereas chemically modified starches, for example, have limitations to be added in foods (Magnuson et al., 2013). The pre-gelatinization of the isolated starches or flours confers characteristics of greater water absorption, contributing to the rapid formation of GFP, which remain homogeneous and with better texture after cooking. Palavecino et al. (2017) made GFPs with a mixture of white sorghum flour, xanthan gum (1.25 to 2.50 g/100 g of flour basis - f.b.), egg white (5.5 to 11 g/100 g f.b.), whole egg (4.5 to 9.0 g/100 g f.b.), and pre-gelatinized corn starch (15 to 30 g/100 g f.b.), and found that the pre-gelatinized corn starch was positively related with an increase of firmness and water absorption index, and a reduction of the cooking loss during cooking.

Some authors adapted the preparation process of GFP aiming to obtain pre-gelatinized fractions. For example, Rachman et al. (2019), used a process of mixture of a banana flour with boiling water (70 g/100 g f.b.) for 20 minutes before using this ingredient for GFP production, which was also used by other authors, as could be observed in Table 1.

Protein

Protein-rich ingredients are frequently used in GFP formulations because the starch network formed in GFPs is considered weak due the lack of an associated gluten network, and can break easily during cooking. The major effect of proteins is the entrapment of the starch granules, helping to reduce the cooking loss, as occurs in conventional pasta (Brockway, 2001). However, so far, no protein source has been able to replace the wheat gluten network.

The high-protein foods, such as egg albumin, with good foaming properties and formation of a three-dimensional network, mainly used in cakes and confectionery products for structuration, are also used in GFP for this same purpose. In contrast, egg yolk proteins, that have emulsifying properties (Paucar-Menacho et al., 2008), can also confer desirable color and smooth texture for the GFPs by its compound's retinol and lecithin, respectively. Some authors have studied egg-derived ingredients in GFP as structuring protein sources, such as dehydrated egg or its protein fractions, such as albumin (Larrosa et al., 2015). In addition to acting as structure-forming agents, these ingredients also contribute to a greater nutritional value, flavor, and for greater acceptance of GFP by consumers.

Other ingredients have also been used for their structuring properties, such as legumes and oilseeds. Laleg et al. (2016) used only legume flours (bean, green lentil, and black-gram) in GFP *spaghetti*-type, and found different firmness, cohesiveness and elasticity behavior when compared to commercial GFP made from maize, millet, and rice flour. Bresciani et al. (2021) evaluated the obtention de GFP made only with yellow lentils flour, concluding that the most suitable production process for these was the thermoplastic extrusion. The pseudo cereals were widely used in gluten-free products, especially in GFPs. They are starchy grains like cereals, with botanical and biochemical differences in the amino acids profile, as they are dicotyledonous plants (Fabio & Parraga, 2017). Their use may be associated with other ingredients, as reported by D'Amico et al. (2015) who studied GFPs with pseudocereals, buckwheat, amaranth, and quinoa, by Demir & Bilgiçli (2021), who used a quinoa flour in partial substitution of a cereal blend (rice and corn semolina). These ingredients could provide structure and nutritional improvement in GFP formulation due to its protein content.

Regional structuring agents and food processing by-products

The use of regional raw materials is an important initiative to stimulate the local economy, since the cost of GFP is high, hampering the adherence to the diet. It was reported in research conducted by White et al. (2016) about the market of GFPs that these products cost 334% more than wheat-based pastas, and its commercialization was limited to specialty food stores and internet sales.

The use of food processing by-products is also an important initiative for reducing economic impacts, and could be used as GFPs ingredients for technological, nutritional, sensory and/or value-added purposes, contributing to sustainability actions, avoiding food waste and promoting changes in the food processing chain. As addressed in Difonzo et al. (2022) review article, fruits and cereals parts as peels, leaves, pomaces, or husks are rich sources of dietary fibers, minerals, vitamins and biocompounds, and could be obtained from different stages of the food processing chain. For example, as reported by Bastos et al. (2016), who studied the use of dehydrated potato pulp flour to GFPs formulations, obtained from residual water from potato chip processing, these ingredients contributed to the acceptability of GFP by the local population, already habituated to the flavor of these foods. In the study of Güngormüşler et al. (2020), the authors formulated GFPs with teff flour, chickpea flour and xanthan gum, and the selected formulation (5 g/100 g f.b. of TF, 10 g/100 g f.b. CF, and 1 g/100 g f.b. XG) presented 33% less carbon footprint when compared to a commercial wheat-based pasta, due to the use of local raw materials and economy of non-renewable resources (as fossil fuels) during transportation.

2.2 Technological improvers

These are ingredients used to facilitate shaping and improve the texture of GFP. Among the additives, those recognized as GRAS stand out, which reinforces the trend towards studies for a healthy appeal of GFPs. A brief description of the technological function of each technological coadjuvant ingredient is presented below:

- *Hydrocolloids:* such as gums, for example, are high molecular weight polysaccharides that have long chains containing many hydrophilic groups (-OH), and forms dispersions in water. They can be used in small quantities due to their high solubility and gelling ability (Saha & Bhattacharya, 2010). The network formed by the hydrocolloids can reduce the cooking loss and contribute to a better texture of GFP (Witczak et al., 2016; Sukchum & Ratphitagsanti, 2018; Demir & Bilgiçli, 2021), also reducing the optimum cooking time and increasing the water absorption capacity (Moura et al., 2016).
- *Emulsifiers:* chemical additives used to stabilize two immiscible phases. In addition, they are widely used in cereal products to delay the starch gelatinization (Witczak et al., 2016; Liu et al., 2012). Thus, the use of emulsifiers can contribute to obtaining a softer GFP after cooking.
- *Vegetable oils:* such as soybean oil (Ferreira et al., 2016), sunflower oil (Larrosa et al., 2015), or vegetable fat (Milde et al., 2020), provides the lubrication needed for cold extrusion and/or shaping processes and reducing the adhesiveness of the dough.

- *Color-conferring ingredients:* most studies have not used artificial colorants. Several authors have studied the use of natural color-conferring ingredients, such as eggs, in GFPs formulations. The yellow color of these products is derived from the presence of carotenoid compounds, which may be important in starch-based pasta or those made from white flour such as rice flour, for example. Among the natural ingredients that add color, we highlight blue maize flour, of Mexican origin (Camelo-Méndez et al., 2018), pumpkin flour (Mirhosseini et al., 2015), and sweet potato flour (Marengo et al., 2018).

2.3 Nutritional improvers

Nutrition enhancers are used to improve the health appeal of GFPs. Table 1 shows some ingredients for nutritional enhancement and their functions in GFP. For nutrition enhancement, we have the proteins and micronutrients. This group also includes the ingredients that contribute to satiety, such as dietary fibers, and those for the control of the glycemic index (GI), such as resistant starch.

Proteic enrichers

Amino acids can be classified as nutritionally essential or non-essential, and an adequate supply of these is a requirement for health maintenance. In GFPs, it is important that proteins possess high digestibility and bioavailability, aiming to improve the intestinal absorption of nutrients (Lamacchia et al., 2014). Legume flours with high protein contents, such as beans (Laleg et al., 2015; Silva et al., 2016), lupine (Linares-García et al., 2019; Albuja-Vaca et al., 2020) and chickpeas (Vijaykrishnaraj et al., 2015; Bouasla et al., 2016; Güngormüşler et al., 2020), are frequently used. The association of legume flours with cereal flours is recommended for complementation of essential amino acids (Marti & Pagani, 2013). Eggs and milk have a complete amino acid profile; thus, they are important ingredients for healthy eating that can be used in GFP. Some authors have studied egg-derived ingredients in GFP as structuring protein sources, such as fresh whole egg (Albuja-Vaca et al., 2020) or dehydrated egg (Larrosa et al., 2015), or its protein fractions, such as albumin (Flores-Silva et al., 2015; Rachman et al., 2019). The use of whole-milk powder was also verified (Milde et al., 2020), as well from marine organisms, as green mussel (Vijaykrishnaraj et al., 2015) and seabass concentrate (Aínsa et al., 2021) as innovative sources of protein in GFPs.

The protein content and amino acids profile of pseudo cereals may contribute to the production of GFP. Amaranth, for example, has a high content of lysine and sulfur amino acids, which can complement cereal flours that are poor in this amino acid, such as rice flour (Bastos et al., 2016). It is desirable that the selected proteins should not be recognized by anti-gliadin antibodies to prevent the inflammatory bowel response in the celiac individual, especially in unconventional protein sources (Susanna & Prabhasankar, 2015). The presence of antinutritional or toxicity compounds, such as phytic acid, protease inhibitors, or cyanogenic compounds, which may be present in legumes, roots, fruits or seeds, should be considered, by adopting measures to eliminate or reduce these compounds at levels that do not cause adverse health effects (Morandini, 2010).

The legume-derived ingredients can be pretreated using heat treatments, for example, whereas GFPs are rapid-cooking products, which may be insufficient for inactivation of its anti-nutritional compounds. According to Sun (2011), the enzymatic hydrolysis in legume flours such as soybean and chickpeas, contributes to the production of GFPs with higher digestibility. Thus, innovative studies are focused on evaluation of the biological processes to increase the digestibility and decrease the anti-nutritional factors. As an example, Marengo et al. (2018) used a non-tannin white sorghum cultivar and evaluated the fermentation and germination processes in the preparation of sorghum flour for use as GFP base, together with pre-gelatinized parboiled rice. The fermentation improved the flavor, structure, and pasta stability, and the substitution of 15 g/100 g (f.b.) was considered ideal. However, the germinated sorghum cannot be used due to its very high enzymatic activities (amylolytic and proteolytic), which can affect the pasta during cooking, dissolving the GFP and impairing its technological quality.

In the study of Laleg et al. (2016), the authors evaluated the anti-nutritional compounds of dried GFP made from raw legume flour, obtained by conventional extrusion and drying at 55 °C for 12 hours. The authors compared the anti-nutritional compounds in the raw flours and the respective cooked GFPs and observed a decrease in the number of trypsin inhibitors, α-galactosides, and phytic acid, but without a complete elimination of these.

Micronutrient and bioactive compounds enrichment

There are few studies evaluating the addition of micronutrients such as vitamins and minerals in GFP, which is a promising field of research, considering that the consumers of GFP may have poor absorption of these nutrients (Tonutti & Bizzaro, 2014). Radoi et al. (2015) evaluated GFPs made from rice flour and different concentrations (10 to 40 g/100 g) of dehydrated banana pulp, fresh banana pulp, and fresh banana pulp treated with ascorbic acid and eggs. The authors observed an increase in the mineral content of the pasta, mainly iron (8.4 to 23.9 mg/kg), manganese (2.6 to 12.3 mg/kg), and zinc (20 to 78 mg/kg). Scarton et al. (2021) studied the use of the biofortified sweet potato flour as an ingredient in rice-based GPFs, obtaining pastas with improvement of provitamin A content.

There are also few studies about bioactive compounds, as antioxidants, anthocyanins, flavonoids, or total phenolic compounds, in GFPs. Recent studies highlight the application of sorghum as a source of dietary fiber and phytochemicals compounds – mostly phenolic acids and flavonoids (Chávez et al., 2018; Célia et al., 2022) - in GFP (Palavecino et al., 2019), and other gluten-free products.

Resistant starch

Resistant starch is defined as the starch portion that is not converted to glucose during the digestive process and has beneficial effects to the glycemic control. According to the review conducted by Raigond et al. (2015), resistant starches can be classified into five types: starch type I, which are physically inaccessible in the plant matrix; type II, which are native, non-gelatinized starch granules; type III, which are digestion-resistant starches from the retrogradation process; type IV, or chemically modified starches; type V, formed by amylose-lipid complexes.

Some authors have studied the addition of sources of resistant starch in GFPs to control the glycemic response among celiac individuals to reduce the risk of developing type II diabetes and obesity. For example, Foschia et al. (2017) studied GFP spaghetti-type made with rice flour and resistant starch type II and found a degradation of 31% of the added RS II during the manufacturing process. Thus, the GFPs-making process should be considered to preserve the maximum nutritional value when using these ingredients.

The addition of resistant starch also promotes technological changes in GFPs. As an example, in a study by Cervini et al. (2021) the authors developed formulations with 5 to 15% of sorghum-derived resistant starch in rice-based GFPs, and found that this ingredient increased firmness, water holding capacity and cooking time, and reduced the loss of solids in cooking.

Soluble and insoluble fiber

Some studies on the inclusion of ingredients rich in fibers in GFP have been reported. Fibers are polymers of non-starch carbohydrates resistant to digestion by humans with health benefits, such as intestinal transit regulation and satiety (Slavin, 2013). In addition, diets with a high concentration of insoluble fiber may reduce the absorption of nutrients, which should be considered for celiac patients or individuals with intestinal sensitivity to gluten (Lamacchia et al., 2014). The authors Bouasla et al. (2016) used legume flour in rice-based GFP and found an increase of cooking loss due to the weakening of the dough structure from the presence of high insoluble fiber content. Thus, the authors recommended the inclusion of soluble fibers to maintain the structure and to provide greater nutritional benefits. The soluble fibers (pectin and gums) are readily hydratable, and some of these forms a high-viscous gel fermentable by intestinal bacteria, with a beneficial prebiotic action to the gastrointestinal tract, which may contribute to individuals with intestinal sensitivity (Lamacchia et al., 2014). In Sakurai et al. (2020) studies, the authors evaluated the application of two ingredients - peach palm meal, and golden linseed in GFPs, obtaining nutritional fiber improvement. Despite its nutritional benefits, it is important to consider that the inclusion of fibers in GFP formulation could lead to technological effects. As example, Llavata et al. (2019) utilized two innovative ingredients in fresh *pappardelle* GFP - tiger nut flour and fenugreek flour – aiming a high fiber content. The increase of these ingredients increased both soluble and insoluble fiber contents, but also increased the hardness and cohesiveness of these pastas. In study with short pastas (*macaroni* type), Sukchum & Ratphitagsanti (2018) evaluated the inclusion of 10 to 20% of fibers from different sources (wheat fiber, corn meal and cellulose fiber) in GFP made with rice flour and tapioca starch (control formulation, 80:20). The increase of fiber content leaded to increase of the cooking loss and to GFP softer than control, due to the interference of the fiber in starch matrix.

Ingredients for glycemic index reduction

The GI indicates how fast blood glucose rises after consuming a carbohydrate-containing food (Goñi et al., 1997). Foods with a low GI contribute to a prolonged sensation of satiety and reduce the risks associated with diabetes and obesity. In conventional wheat-based pasta, the gluten protein network has an effect on the reduction of the GI, because it forms a network around the starch granules, impairing the access of the digestive enzymes to the starch (Brockway, 2001). In GFP, this reduction may not occur, especially in formulations based in starch and reduced amounts of fiber and proteins (Lamacchia et al., 2014; Lee & Newman, 2003).

The authors Menga et al. (2017) studied the addition of 5 to 10 g/100 g (f.b.) of chia seeds or its mucilage in long rice flour-based GFP *tagliatelle*-type made by conventional cold extrusion, and also evaluated the possibility of using those seeds as a substitute for hydrocolloids and the carbohydrate *in vitro* digestibility of these pastas. They observed that the ground seeds contributed to the reduction of the digestion rate due to the presence of polyunsaturated fatty acids, which increased the viscosity and reduced the amylase activity. The use of 10 g/100 g (f.b.) of chia seeds mucilage provided a more nutritious GFP with higher protein, dietary fiber, and phenolic acids contents when compared to a commercial control maize starch-based pasta.

3 Processing of gluten-free pastas

There are low investments in research and development of processes and suitable equipment for GFPs production, when compared with the conventional pasta (Heller, 2009; Shewry, 2009; Marti & Pagani, 2013). As shown in Table 1, the GFP can be produced and formatted from several processes such as lamination, conventional cold extrusion or thermoplastic extrusion. To provide resistance, various processes can be used to enhance the GFPs shape maintenance during the production, transport, and commercialization steps, such as thermoplastic extrusion.

The combination of high pressure and heat in this process leads to a pre-gelatinization of the starch and protein denaturation, which helps in the formation of the pasta structure and allows the production of instant pasta (Bouasla et al., 2016). Although there are more studies on dry and long GFPs, those may present disadvantages such as higher cracks and defects occurrence, especially during drying, packaging, transport, and storage, due to the fragility of the pasta structure. Thus, the production of short dry GFP can be a technological alternative to reduce the losses during process and storage. The combination of ingredients and processes suitable for the production of GFP is essential, thus research on these products should be encouraged to meet the consumer expectations and offer products that are nutritionally rich and attractive from the sensory point of view.

4 Conclusion

The development of GFP with better technological and nutritional characteristics has been possible since new ingredients and processes have been studied. Regional ingredients that are sources of protein, starch and insoluble fiber, and additives, such as gums, are among the most used ingredients in GFPs formulations. The biggest challenge remains the texture of these pastas after cooking, once the sensory characteristics such as color, overall appearance, and flavor have already been widely studied. In this review, we could propose the following guidelines for the GFP, concerning about:

- *The ingredients* – utilization of protein sources free from anti-nutritional or toxic factors; preference for ingredients that increase satiety and reduce the glycemic index, such as soluble fibers and resistant starches;
- *The processing* – choose conditions that preserve the bioactive compounds, and that contribute to the structuring of GFP and reduce the number of additives, for example, production of instant pasta or precooked pasta.

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