What can play the role of gluten in gluten free pasta?

Alessandra Marti and Maria Ambrogina Pagani*

Department of Food, Enviromental, and Nutritonal Sciences - DeFENS, Università degli Studi di Milano, via G. Celoria 2, 20133 Milan, Italy

* corresponding author: Maria Ambrogina Pagani

ambrogina.pagani@unimi.it

Tel.: +39 02 50316658.

via G. Celoria 2, 20133 Milan, Italy

Highlights

- The strategies used for the replacement of gluten functionality in pasta were reviewed
- The effects of treatments on raw-materials were examined
- The effects of processing conditions on starch properties and pasta quality were considered

ABSTRACT:

Defining and optimizing the technological process to improve the sensory and nutritional characteristics of gluten-free (GF) products still represent a challenge for researchers and industry. As regards pasta, several ingredients (modified starch, GF flours, additives) have been used as alternatives to gluten in order to create a starchy network that can withstand the physical stresses of cooking and impart firmness to the cooked product. Moreover, different variations of noodle-making technology have been proposed to simplify the artisan process based on repeated heating and cooling steps, which are difficult to control and monitor. This paper will overview how to replace gluten functionality in GF pasta.

INTRODUCTION

The popularity of pasta is increasing worldwide, thanks to its convenience, palatability, long and easy shelf-life, and, last but not least, its nutritional properties. In addition to the conventional pasta-product made from durum wheat semolina, it is common to enrich pasta with some cereals (barley, rye, etc.), pseudocereals (buckwheat, amaranth, quinoa), and legume flours (pea, chickpea, etc.), to provide sources of fiber, minerals, antioxidants, and polyphenols. In the last few decades, a third group of pasta-products, the gluten-free (GF), is being consumed not only by the growing number of celiacs but also by others who wish to exclude gluten-based products from their diet for health reasons. Moreover, as celiac disease can occur at any age, the production of good quality GF products for people with a tradition consuming of wheat-based products is necessary as an alternative. Currently, there is a broad variety of GF products available for celiacs made from rice, corn, and other GF flours. Unfortunately, most of them exhibit poor cooking quality, particularly when compared with their wheat counterparts (Hager, Zannini & Arendt, 2012; Lucisano, Cappa, Fongaro & Mariotti, 2012). Moreover, many GF products are nutritionally inferior, i.e. poorer in minerals and bio-components, to the wheat-based foods they are intended to replace. These findings suggest that more attention should be paid to the nutritional and sensory quality of GF products. At this regard, recently, the possibility of using green banana flour to produce pasta products with bioactive compounds, such as resistant starch and phenolic acids, was also investigated by Zandonadi et al. (2012). Although the demand for better-tasting, better-textured, and healthier GF products offers great market opportunities for food manufacturers, the replacement of gluten functionality still presents a major technological challenge. The degree of difficulty in producing GF products is closely associated with the technological role of gluten in the food-system. Cookies, whose texture mainly depends on sugar and fat to assure crispness and friability, are the easiest to formulate without gluten because it plays a secondary role in their making and end-product quality (Engleson & Atwell, 2008). The most challenging products to formulate and produce are GF bread and pasta, as gluten is their architectural key. The few papers published in the last decade (FSTA database) on GF pasta (about 20, excluding patents) indicates the difficulty of this task.

GLUTEN FUNCTIONALITY IN PASTA FROM DURUM-WHEAT SEMOLINA

Pasta is considered one of the simplest cereal-based products in terms of ingredients (only two: semolina and water) and processing (a sequence of hydration, mixing, forming, and drying steps). Both raw-material characteristics and processing conditions play a key role in determining the quality of final pasta products (De Noni & Pagani, 2010). Protein quantity and quality have received considerable attention as the most important factors affecting pasta properties (D'Egidio, Mariani, Nardi, Novaro & Cubadda, 1990). A high protein content and a "strong" gluten (in terms of its visco-elasticity) are required to process semolina into a suitable final pasta product with an optimal cooking performance (D'Egidio, Mariani, Nardi, Novaro & Cubadda, 1990; Feillet & Dexter, 1996). Microscopic observations have revealed that the gluten network in dried pasta is more or less uniformly and regularly arranged around starch granules according to the quality of the semolina used (Resmini & Pagani, 1983). On the contrary, starch in dried pasta is still in the form of whole native granules, as in semolina. During cooking, starch and protein exhibit completely different behaviors. The starch granules rapidly swell, tend to disperse, and become partly soluble. While, proteins become completely insoluble and coagulate, creating a strengthened network, which traps starch material (Resmini & Pagani, 1983). Starch gelatinisation and protein coagulation are both competitive phenomena, occur at the same temperature and are influenced by water availability (Pagani, 1986). The faster the formation of a continuous protein network, the more limited the starch swelling, thus ensuring firm consistency and the absence of stickiness in pasta (Resmini & Pagani, 1983). On the contrary, if the protein network lacks elasticity or its formation is delayed, starch granules will easily swell, and part of the starchy material will pass into the cooking water, resulting in a product characterized by stickiness and poor consistency (Resmini & Pagani, 1983).

HOW TO REPLACE GLUTEN FUNCTIONALITY IN GLUTEN FREE PASTA

While gluten proteins play a key role in conventional semolina pasta properties, starch is the determining component in GF pasta only if it can re-organize the macromolecular structure in an efficacious way giving a texture similar to that found in semolina products. Pasta companies can adopt different approaches to reach this goal. In any case, starch has to assume a structuring role, which is related to the tendency of its macromolecules to re-associate and interact after gelatinization, resulting in newly organized structures that retard further starch swelling and solubilisation during cooking. Despite this well known fact, few studies have dealt with starch organization in GF pasta. In the late '80s, Mestres, Colonna & Buleon (1988) investigated the starch network of GF noodles using DSC and X-rays, and found that new crystalline organizations were formed as a consequence of starch retrogradation. Amylose-based structures were present in retrograded form (B-type) and the good cooking behaviour of rice noodles was mainly attributed to amylose networks. More recently, Marti, Seetharaman, & Pagani (2010) and Marti, Pagani & Seetharaman (2011a,b) observed that the average molecular weight of amylose and amylopectin, as well as their molecular organization within the granule, affected starch functionality and, consequently, cooking performance.

Basically, in GF pasta, the role of gluten could be replaced by choosing suitable formulations and recipes using heat-treated flours as the key-ingredients, or by adopting non-conventional pasta-making processes to induce new rearrangements of starch macromolecules.

GLUTEN-FREE PASTA FORMULATION

The common ingredients in GF pasta are flour and/or starch from corn, rice, potato (or other tubers), with the addition of protein, gums, and emulsifiers which may partially act as substitutes for gluten. The diversity of GF raw materials help to increase the quantity and the quality of products for celiacs.

Formulating GF pasta requires, firstly, a thorough knowledge of the component properties of GF flours and starches. Then, appropriate additives may be selected to promote a cohesive mass in the product.

THE PROPERTIES OF GLUTEN FREE STARCHY FLOURS

The ideal starch for GF pasta products should have a marked tendency to retrograde: this property, generally observed in high amylose cereals and pulses, assures good cooking behaviour in terms of texture and low cooking loss, even after prolonged cooking (Lii & Chang, 1981; Bhattacharya, Zee & Corke, 1999). Mung bean starch is considered one of the best raw material for producing high quality starch spaghetti, due to its high amylose content and type C viscoamylogram pasting profile, characterized by the absence of a peak and the presence of a constantly increasing viscosity during heating and shearing, indicative of good hot-paste stability (Lii & Chang, 1991).

Today, GF flours are used more than starches, thus skipping the expensive stage of starch extraction from the grains. Furthermore, from a technological point of view, the use of flours allows to exploit the presence of interactions between starch and other components, such as proteins and lipids.

Despite scientific efforts to determine the physico-chemical properties of GF raw materials as they relate to the final quality of noodles (Bhattacharya; Zee & Corke, 1999; Tam, Corke, Tan, Li & Collado, 2004), the selection of raw-materials for GF pasta production is currently based solely on checking for the absence of gluten, while neglecting the evaluation of starch characteristics of GF flours. In fact, GF industries prefer using peculiar heat-treatments or additives for improving the cooking behaviour of GF pasta products.

Rice

Rice (as flour or starch) is present in practically all GF products in the market. Frequently rice flour is produced starting from broken grains which are removed during milling since they decrease the commercial quality of whole grain rice.

Traditional rice noodles are made from long-grain rice flour with intermediate-to-high amylose content (> 22 g/100 g), which plays a pivotal role in creating a starch network in rice noodles (Kohlwey, Kendall & Mohindra, 1995). Several studies have assessed the quality of noodles made from different rice varieties. On the basis of sensory evaluation, Sanchez (1975) found a highly significant correlation between high amylose content and panel acceptability. Chen & Luh (1980) reported that the swelling capacity of starch and amylose-amylopectin ratio are the two major factors affecting rice noodle quality. Li & Luh (1980) noted that rice varieties with high amylose content, low gelatinisation temperature, and hard gel consistency were best suited for making noodles. These findings were confirmed some years later, when a good correlation between physico-chemical properties and the texture of vermicelli was found (Bhattacharya; Zee & Corke, 1999).

Little attention has actually been paid to flour from brown rice, despite its high nutritional value related to dietary fibre, phytic acid, vitamins E and B, and aminobutyric acid (GABA): these components are present in relevant quantities in the bran layers and germ which are removed during the polishing (or milling step) to obtain milled rice. Recently, Marti, Seetharaman & Pagani (2010) prepared GF pasta from brown rice flour. The higher fibre content in brown rice was responsible for a weakening of the starch network and consequently for the increase in cooking loss. At the same time, the inclusion of fibre in the starch matrix partially reduced the extreme firmness and springiness found in pasta from milled rice flour.

Corn

Amylose in corn noodles has also been indicated as the component accounting for their textural integrity after cooking. Dexter & Matsuo (1979) showed that in corn blends, the lower the amylose content, the lower the noodle cooking quality. However, corn starches with high amylose contents (>40%) don’t provide a sufficient degree of gelatinisation during the heating process, limiting the extent of the following starch retrogradation (Tam, Corke, Tan, Li & Collado, 2004). Corn starches with amylose contents of around 26-28% were successfully used for bihon-type noodle production (Tam, Corke, Tan, Li & Collado, 2004).

Mestres, Colonna, Alexandre & Matencio (1993) studied the effects of various heat-treatments (drum-drying, extrusion-cooking, pasting with hot water, or steaming) on corn pasta properties. The best cooking quality was observed using the drum-drying process, even if no reason was given. Waniska *et al.* (1999) investigated the effects of several parameters on corn noodle quality. Preheating the mixture of corn flour and water (43-45% moisture) at 90-95 °C was required to successfully extrude noodles using a pasta-maker. Adding more water to noodle production resulted in higher gelatinisation, which is associated with longer cooking times and lower cooking losses (Waniska *et al.*, 1999).

Sorghum

The grain presents interesting characteristics from a nutritional standpoint, as it is a source of protein, starch, and antioxidant compounds. For this reason, a potential novel use of sorghum could be the manufacture of pasta products, in addition to or as a substitute for corn or rice flours in the preparation of GF food.

Suhendro, Kunetz, McDonough, Rooney & Waniska (2000) investigated the effect of the cultivar, flour particle size, and processing conditions on the cooking quality of noodles prepared from flour of decorticated sorghum on laboratory scale. The fine flour preheated in a microwave oven and dried using the two-stage method produced the best noodles with moderate dry matter loss. Noodles from waxy sorghum proved to be of inferior quality compared to normal sorghum. Such noodles were soft and sticky, with high losses during cooking, probably as a consequence of limited retrogradation extent (Suhendro, Kunetz, McDonough, Rooney & Waniska, 2000).

Recently, flour from fermented sorghum was mixed to brown rice flour to prepare GF pasta (Pagani *et al.*, 2010). The modification of the structural and physical properties promoted by fermentation improved pasta quality with respect to the sample from unfermented sorghum.

Pseudo-cereals

Amaranth, quinoa, and buckwheat are becoming increasingly popular because they improve the nutritional quality of GF products, in terms of high fibre, vitamins, minerals, and other bioactive components (polyphenols, phytosterols, etc.) (Alvarez-Jubete, Arendt & Gallagher, 2010). Despite the few published data on oat-enriched GF pasta, oat flour is not commonly used as ingredients for GF formulations. In fact, a number of early studies produced conflicting results and most gastroenterologists have been cautious and recommended avoidance of oats.

Good quality spaghetti were produced from blends of corn, soy, oat, and quinoa (5-15%) flours (Caperuto, Amaya-Farfan & Camargo, 2001; Chillo *et al.*, 2009; Mastromatteo, Chillo, Iannetti, Civica & Del Nobile, 2011). GF macaroni from blends of quinoa and rice flour obtained by extrusion at 60 and 77 °C have also been successfully produced (Borges, Ramirez Acheri, Ramirez Ascheri, Do Nascimento & Freitas, 2003). By blending buckwheat, amaranth, and quinoa in different ratios by means of an experimental design (along with the addition of albumen, emulsifier, and enzymes), Schoenlechner, Drausinger, Ottenschlaeger, Jurackova & Berghofer (2011) improved the cooking quality of GF pasta. The best product was prepared from a combination of amaranth, quinoa, and buckwheat (40:40:60), with 6% of egg white powder and 1.2% of emulsifier. More recently, Cabrera-Chávez *et al.* (2012) prepared amaranth-supplemented GF pasta, observing that the incorporation of amaranth to rice flour (25:75 ratio), combined with the cooking-extrusion process, improved the nutritional quality of pasta, while maintaining good cooking behaviour.

THE USE OF ADDITIVES AND TEXTURING INGREDIENTS

Pasta prepared only from non-gluten flour is generally considered to be inferior in textural quality compared to semolina pasta: it does not tolerate overcooking, it is sticky, and, above all, it is characterized by relevant cooking losses. Adding texturing ingredients can be a simple solution for improving pasta cooking behaviour by decreasing these defects.

Hydrocolloids or gums are commonly used for their ability to make a gel in little quantities, provide high consistency at room temperature, improve firmness, give body and mouthfeel to pasta. In addition, because of their ability to bind water, gums can increase the rehydration rate of pasta (Sozer, 2009). A wide range of hydrocolloids have been proposed: arabic gum, xanthan-gum, locust bean gum, carboxymethylcellulose (CMC), etc.

Emulsifiers act as lubricants in the extrusion process and provide firmer consistency and a less sticky surface, as they control starch swelling and leaching phenomena during cooking (Lai, 2002), thereby improving the texture of the final product (Kaur, Singh & Singh., 2005; Charutigon, Jitpupakdree, Namsreem & Rungsardthong, 2008).

Despite the several well-known positive effects of the addition of emulsifiers and hydrocolloids (Huang, Knight, & Goad 2001; Lai, 2002; Singh, Raina, Bawa & Saxena, 2004; Kaur, Singh & Singh., 2005; Chillo, Laverse, Falcone & Del Nobile, 2007; Charutigon, Jitpupakdree, Namsreem & Rungsardthong, 2008; Sozer, 2009) consumers often associate their presence in GF pasta to an "artificial" food. Consequently, the use of proteins as structuring building ingredients represents an interesting alternative for producing GF pasta, not to mention its positive nutritional effects (Thompson, 2009). In this regard, recent studies found an improvement in pasta texture when egg and milk proteins were used in GF formulations (Chillo *et al.*, 2009; Sozer, 2009; Schoenlechner, Drausinger, Ottenschlaeger, Jurackova & Berghofer, 2011).

THE OPTIMIZATION OF GF PASTA-MAKING PROCESS

Up to now, GF pasta made from solely GF flour has usually been prepared in one of two ways. The first approach focuses on the use of heat-treated flours, in which starch is already mostly gelatinized. Here, the pre-treated flour can be formed into pasta by the continuous extrusion press commonly used in durum wheat semolina pasta-making. In the second technological approach (extrusion-cooking process), native flour is treated with steam and extruded at high temperatures (more than 100°C) for promoting starch gelatinization directly inside the extruder-cooker. Marti, Caramanico, Bottega & Pagani (2012) applied both these processes to native rice flour, without additives or structuring ingredients. Because a regular and continuous protein network was lacking, starch polymers were less efficaciously entrapped in the rice matrix, resulting in a product with high cooking losses (10g/100g), two-three times higher than those of pasta from durum wheat semolina. As regards the texture, pasta prepared from pre-gelatinized flour (Pasta A) exhibited higher firmness compared to that of pasta from extrusion-cooking of native flour, using a single-screw extruder (Pasta B). The ultrastructure images reported in Figure 1 highlighted differences in starch arrangement inside the two products. At the beginning of cooking, Pasta A showed a compact and homogeneous matrix (Figure 1a). On the contrary, the mere immersion of Pasta B in hot water induced a great disruption of surface structure (Figure 1b), accounting for the high water absorption (91 g/100g and 78g/100g, by Pasta B and Pasta A, respectively) and the low firmness (190 N and 310 N for Pasta B and Pasta A, respectively). In addition, the extrusion-cooking of native rice was not efficacious in creating a continuous and smoothed starchy matrix, since some aggregates are still recognizable (Figure 1c).

Recently, Chillo *et al.* (2010) investigated the effect of the repeated extrusion steps (at temperatures below 46°C) on the sensory characteristics of GF spaghetti. This processing promoted the formation of a compact structure in the dried product. But, the application of shear stress without the combination of high temperature was not efficacious in promoting starch gelatinisation, and thus there was no improvement in the sensory quality of the cooked pasta.

Careful selection of processing conditions is the starting point for promoting new starch arrangements in GF raw materials to assure good cooking behaviour and effective structure, not only for the texture but also for nutritional properties in terms of enzyme accessibility and starch digestibility.

FROM TRADITIONAL NOODLE-MAKING PROCESS TO THE CURRENT TECHNOLOGIES

GF pasta-making is still based on ancient but still-in-use processes for making Oriental starch noodles. As the main ingredient of GF raw-materials, starch plays a key role in noodle production. Non-gluten noodle-technology is mainly based on dough heating and cooling operations, that exploit two phenomena: firstly starch gelatinisation and, then, its retrogradation. The greater the degree of starch gelatinisation, the better the cooking quality. On the contrary, a slight starch swelling is related to pasta disruption during cooking due to the lack of a continuous network of retrograded starch (Pagani, 1986). For this reason the traditional noodle-making process suggests heat-treatments at high temperatures (90-95 °C) during extrusion, which may be repeated several times (Tan, Li & Tan, 2009). During the cooling steps, new and spontaneous starch crystallization occurs, resulting in a translucent, vitreous, and consistent product. These modifications promote a loss of starch granular structure during gelatinisation, and an extensive reticular and fibrillar network after cooling (Resmini & Pagani, 1983).

Even if the highly reticulated starch network can account for the good cooking quality of the artisanal pasta, traditional Oriental noodle-technology is difficult to transfer to an industrial scale. Controlling gelatinisation and retrogradation phenomena is hard and requires many hours of work and high amounts of energy and water to heat and cool the dough. Moreover, the size or the diameter of the product is a critical factor: the thin layer of noodles (diameter of 0.68-0.78 mm) is essential in decreasing the sensory perception of extreme hardness and springiness in a product characterized by a strong degree of retrogradation.

Considering all these disadvantages, the use of pre-heated flour or extrusion-cooking processed flour bypasses the steps of the discontinuous process (steaming, cooking in boiling water, and cooling), thus simplifying traditional noodle making technology.

EXTRUSION-COOKING PROCESS

Extrusion-cooking is one of the most suitable technologies for GF pasta-making. Extrusion-cooking consists of using high temperature for a relatively short time, and is commonly used for producing several food items (pre-gelatinized starch, snacks, ready-to-eat breakfast cereals, etc.). The main phenomenon associated with the extrusion-cooking used and exploited in GF pasta-making is again starch gelatinisation. In fact, starch granule organisation is disrupted to render it digestible and to produce a malleable product. In other words, the crystalline starch macromolecules are converted into a more amorphous material, as recently reported by Wolf (2010).

Tsao (1976) was one of the first authors to apply extrusion-cooking to make rice spaghetti. More recently, the suitability of pea starch and pea flour for pasta-making using a twin-screw cooking-extruder was investigated (Wang *et al.*, 1999; Vasanthan & Li, 2003). Pasta obtained by extrusion-cooking exhibited superior firmness, flavour, and texture after cooking, compared to pasta-products prepared from the same flour using a conventional extruder (Wang *et al.*, 1999). Extrusion-cooking has been successfully used for pasta production from corn (Budelli & Fontanesi, 2007; Merayo, Gonzalez, Drago, Torres & De Greef, 2011; Giménez et al., 2013). The GF flour was first heat-treated in an extruder by contact with a heated wall and/or steam injection, and then, extruded, formed and shaped, and finally dried. A certain degree of cooking has to be reached so as to obtain pasta with good cooking characteristics and resistance to overcooking (Merayo, Gonzalez, Drago, Torres & De Greef, 2011; Giménez et al., 2013).

THE USE OF PRE-TREATED FLOURS

The use of pre-treated flours, whereby starch is disorganized by pre-cooking it in a separate plant before pasta-making, is one of the processes currently used to prepare GF pasta. In this regard, several heat-treatments have been proposed and each of them specifically affects starch properties (Table 1). Physical treatments have also been applied to starches to alter their native physiochemical properties in order to meet various industrial needs (Zavareze, Storck, de Castro, Schirmer & Dias, 2010). Understanding the nature of the changes could help determine the choice of efficacious treatments on starch for the GF pasta sector.

Annealing (ANN), consisting in the treatment of starch in excess of water (more than 40%) at a temperature below gelatinisation (for rice 50-60°C), and heat-moisture treatment (HMT; treatment at low moisture and high temperatures, 100-120°C for rice) are hydrothermal processes often used in modifying the native physiochemical properties of starch (Jacobs & Delcour, 1998). Both ANN and HMT increase starch crystallinity, granule rigidity, and polymer chain associations (Jacobs & Delcour, 1998; Tester & Debon, 2000). These particular hydrothermal treatments suppress granule swelling, retard gelatinization, and increase starch paste stability (Hoover & Vasanthan, 1994; Hormdok & Noomhorm, 2007), thus improving cooking behaviour and texture properties of rice noodles (Yoenyongbuddhagal & Noomhorm, 2002; Hormdok & Noomhorm, 2007). In addition, Cham & Suwannaporn (2010) optimized hydrothermal treatment conditions to obtain rice noodles exhibiting different cooking qualities. ANN is suitable for preparing fresh rice noodles that require a soft texture, whereas HMT is more appropriate for semi-dried and dried noodles characterized by high tensile strength and gel hardness.

Despite the improvements associated with the use of ANN and HMT flours, the use of pre-gelatinized flour is generally considered a cheaper approach for improving rice noodle quality. Raina, Singh, Bawa & Saxena, (2005) reported that the textural quality of both uncooked and cooked pasta improved significantly when pre-gelatinized rice flour was used. Moreover, the intensity of flour pre-gelatinisation plays a very important role in imparting a desirable noodle texture. Although gelatinisation is required to produce the binding effect during extrusion, excessive gelatinisation may cause extremely high extrusion pressures (Juliano & Sakurai 1985). More recently, Yalcin & Basman (2008a) investigated the effect of the gelatinisation level of rice flour on noodle cooking behaviour. Samples obtained with 25% gelatinisation level exhibited lower cooking loss and better tolerance during cooking compared to samples prepared with 15, 20, or 30% gelatinisation level. Other works noted that the effects of gelatinisation extent on the final product depended on the cereal variety and processing conditions used. In the case of corn, noodles containing 80% gelatinised corn flour exhibited the best cooking and sensory properties (Yalcin &

Basman, 2008b). The hydration level and the time-temperature conditions of the pre-gelatinisation process significantly affected the pasta-making process and the cooking quality of rice pasta (Lai, 2002). Low hydration level (400g water/kg flour) and steaming for short times and low temperatures (85°C for 10 min) resulted in the formation of rice dough that easily extruded into pasta. On the contrary, rice dough prepared using a high hydration level and high gelatinisation was too viscous to be extruded (Lai, 2002). More recently, Marti (2010) reported that the substitution of 50% rice flour with pre-gelatinized flour improved the quality of the pasta. These authors supposed that the pre-gelatinized flour may have acted as a binder, re-polymerizing into a network around the starch granules of rice flour during the extrusion step, because of the different gelatinization temperatures of the two flours, thereby increasing their tolerance to cooking stress, as Pagani (1986) suggested too.

Pre-gelatinized flours is currently preferred by GF pasta companies also because it can be used in the same conventional press for semolina pasta. However, some technological know-how has to be used. In GF pasta production, the amount of water added to the pre-gelatinized flour has to calculated by taking into account the higher water affinity of this raw-material. Generally, the final moisture of dough could amount to 40% of the mixture (Marti, Seetharaman & Pagani, 2010), higher than in semolina dough (approximately 30% moisture; Dalbon, Grivon & Pagani, 1996).

Recently, Grugni, Mazzini, Viazzo & Viazzo (2009) patented the use of parboiled rice in GF pasta production. Parboiling, carried out on paddy rice, promotes changes in the physicochemical, nutritional, and sensory properties of the kernel: starch gelatinizes, part of the vitamins and minerals migrate towards the endosperm, and a lipid-amylose complex is formed, restricting starch swelling and amylose leaching during cooking (Bhattacharya, 2004). These modifications on starch organization are responsible for decreasing stickiness and increasing hardness of the cooked kernels (Bhattacharya, 2004). Marti, Seetharaman & Pagani (2010) demonstrated that the use of flour from parboiled rice promoted the formation of a new macromolecular structure, resulting in good texture after cooking, also according to the parboiling conditions (steeping temperature) (Marti, Seetharaman & Pagani, 2010; Marti, 2010). Further, the strong interactions of amylopectin and/or amylose promoted by the extrusion-cooking process suggested that the amylopectin matrix is likely a combination of amylose and amylopectin chains. By using parboiled rice flour, the traditional recipe for producing pasta (flour and water) are maintained, while additives (such as modified starches, gums, mono and diglycerides of fatty acids, etc.) are avoided.

CONCLUSIONS

Despite the great efforts made in the last few decades to produce GF pasta with sensory characteristics similar to durum wheat products, the GF pasta currently on the market is still far from what the consumer is looking for. Moreover, little information is available regarding starch arrangements that can guarantee good quality cooking. In fact, up-to-now only a few works have investigated the molecular starch organizations induced by different treatments and how these impact on pasta cooking behaviour. Most studies adopt an empiric approach: varying ingredients and processing conditions rather than understanding the macromolecule organization associated with good or poor cooking quality. Moreover, most of the few studies published refer to laboratory scale pasta-making, neglecting its transfer to an industrial scale. Understanding the relationship between starch structure and processing conditions will help the industry re-formulate and develop products with the desired texture as well as improved nutritional and digestive properties.

References

Alvarez-Jubete, L., Arendt, E.K., & Gallagher, E. (2010). Nutritive value of pseudocereals and their increasing use as functional gluten-free ingredients. *Trends in Food Science and Technology, 21,* 106-113.

Bhattacharya, M., Zee, S.Y., & Corke, H. (1999). Physicochemical Properties Related to quality of rice noodles. *Cereal Chemistry, 76,* 861-867.

Bhattacharya, K. R. (2004). Parboiling of rice. In E.T. Champagne, (Eds.), *Rice: Chemistry and Technology* (pp. 329-404). St. Paul: The American Association of Cereal Chemists.

Borges, J.T. da S., Ramirez Acheri, J. L., Ramirez Ascheri, D., Do Nascimento, R. E., & Freitas, A. S. (2003). Cooking properties and physico-chemical characterization of precooked macaroni of whole quinoa (Chenopodium quinoa Willd) flour and rice (Oryza sativa L.) flour by extrusion cooking. *Boletim Centro de Pesquisa de Processamento de Alimentos, 21,* 303-322.

Budelli, A, & Fontanesi, M. (2007). Gluten-free pasta and dough, use of the dough and process for preparing same. EP 1749450 A1.

Cabrera-Chávez, F., Calderon de la Barca, A., Islas-Rubio, A. R., Marti, A., Marengo, M., Pagani, M.A., Bonomi, F., & Iametti, S. (2012). Molecular rearrangements in extrusion processes for the production of amaranth-enriched, gluten-free rice pasta. *Food Science and Technology, 47,* 421-426.

Caperuto, L.C., Amaya-Farfan, J., & Camargo, C.R. (2001). Performance of quinoa (Chenopodium quinoa Willd) flour in the manufacture of gluten-free spaghetti. *Journal of Food and Agriculture, 81,* 95-101.

Cham, S., & Suwannaporn, P. (2010). Effect of hydrothermal treatment of rice flour on various rice noodles quality. *Journal of Cereal Science, 51,* 284-291.

~~Chan, P.S.K., Chen, J., Ettelaie, R., Law, Z., Alevisopoulos, S., Day, E., & Smith, S. (2007). Study of the shear and extensional rheology of casein, waxy maize starch and their mixtures. *Food Hydrocolloids, 21,* 716-725.~~

Charutigon, C., Jitpupakdree, J., Namsreem P., & Rungsardthong, V. (2008). Effects of processing conditions and the use of modified starch and monoglyceride on some properties of extruded rice vermicelli. *Food Science and Technology, 41,* 642-651.

Chen, S.Y., & Luh, B.S. (1980). Chemical, physical and cooking properties of rice vermicelli. In Proceeding of Rice Technology. Working Group, 18th. Texas A&M University, College Station, TX, USA.

Chillo, S., Laverse, J., Falcone, P.M., & Del Nobile, M.A. (2007). Effect of carboxymethylcellulose and pregelatinized corn starch on the quality of amaranthus spaghetti. *Journal of Food Engeneering, 83,* 492-500.

Chillo, S., Civica, V., Iannetti, M., Suriano, N., Mastromatteo, M., & Del Nobile, M.A. (2009). Properties of quinoa and oat spaghetti loaded with carboxymethylcellulose sodium salt and pregelatinized starch as structuring agents. *Carbohydrate Polymers, 78,* 932-937.

Chillo S, Civica V., Iannetti, M., Mastromatteo, M., Suriano, N., & Del Nobile, M.A. (2010). Influence of repeated extrusions on some properties of non-conventional spaghetti. *Journal of Food Engineering, 100,* 329-335.

Dalbon, G., Grivon, D., & Pagani, M.A. (1996). Continuous manufacturing process. In J.E. Kruger, R.R. Matsuo, & J.W. Dick (Eds.), *Pasta and Noodle Technology* (pp. 13-58). St. Paul: The American Association of Cereal Chemists.

D'Egidio, M.G., Mariani, B.M., Nardi, S., Novaro, P. and Cubadda, R. (1990). Chemical and technological variables and their relationships: A predictive equation for pasta cooking quality. *Cereal Chemistry, 67*, 275-281.

Dexter, J.E., &Matsuo, R.R. (1979). Effect of starch on pasta dough rheology and spaghetti cooking quality. *Cereal Chemistry, 56,* 190-195.

De Noni, I, & Pagani, M.A. (2010). Cooking properties and heat damage of dried pasta as influenced by raw material characteristics and processing conditions. *Critical Review in Food Science and Nutrition, 50,* 465-472.

Dias, A.R.G., Zavarese, E. da R., Spier, F., de Castro, L.A.S., & Gutkoski, L.C. (2010). Effects of annealing on the physicochemical properties and enzymatic susceptibility of rice starches with different amylase contents. *Food Chemistry, 123,* 711-719.

Engleson, J., & Atwell, B. (2008). Gluten-free product development. *Cereal Foods World, 53,* 180-184.

Feillet, P. & Dexter, J.E. (1996). Quality requirements of durum wheat for semolina milling and pasta production. In J.E. Kruger, R.R. Matsuo, & J.W. Dick (Eds.), *Pasta and Noodle Technology* (pp. 95-131). St. Paul: The American Association of Cereal Chemists.

Giménez, M.A., Gonzalez, R.J., Wagnerc, J., Torres, R., lobo, M.O., Samman, N.C. (2013). Effect of extrusion conditions on physicochemical and sensorial properties of corn-broad beans (*Vicia faba*) spaghetti type pasta. *Food Chemistry, 136,* 538-545.

Grugni, G. Mazzini, F., Viazzo, G., & Viazzo, N. (2009). Process for the production of rice pasta and product obtained thereby. EP 2110026 A1.

Hagenimana, A., Ding, X., & Fang, T. (2006). Evaluation of rice flour modified by extrusion cooking. *Journal of Cereal Science, 43,* 38-46.

Hager, A.S., Zannini, E., & Arendt, E., K. (2012). Gluten-free pasta: advances in research and commercialization. *Cereal Foods World, 57,* 225-229.

Hoover, R., & Vasanthan, T. (1994). Effect of heat-moisture treatment on the structure and physicochemical properties of cereal, legume, and tuber starches. *Carbohydrate Research, 252,* 33-53.

Hormdok, R., & Noomhorm, A. (2007). Hydrothermal treatments of rice starch for improvement of rice noodle quality. *Food Science and Technology, 40,* 1723-1731.

Huang, J.C., Knight, S., & Goad, C. (2001). Model prediction for sensory attributes of non-gluten pasta. *Journal of Food Quality, 24,* 495-511.

Jacobs, H., Eerlingen, C., Clauwaert, W., & Delcour, J.A. (1995). Influence of annealing on the pasting properties of starch from varying botanical sources. *Cereal Chemistry, 72,* 480-487.

Jacobs, H., & Delcour, J.A. (1998) Hydrothermal modifications of granular starch, with retention of the granular structure: a review. *Journal of Agriculture and Food Chemistry, 46,* 2895-2905.

Juliano, B.O., & Sakurai, J. (1985). Miscellaneous products. In B.O. Juliano (Eds), *Rice: chemistry and technology* (pp. 569-618). St. Paul: The American Association of Cereal Chemists.

Kaur, L., Singh, J., & Singh, N. (2005). Effect of glycerol monostearate on the physico-chemical, thermal, rheological and noodle making properties of corn and potato starches. *Food Hydrocolloids, 19,* 839-849.

Kohlwey, D.E., Kendall, J.H., & Mohindra, R.B. (1995). Using the physical properties of rice as a guide to formulation. *Cereal Foods World, 40,* 728-732.

Lai, H.M. (2002). Effects of rice properties and emulsifiers on the quality of rice pasta. *Journal of Science and Food Agriculture, 82,* 203-216.

Lai, H.M., & Cheng, H.H. (2004). Properties of pregelatinized rice flour made by hot air or gum puffing. *International Journal of Food Science and Technology, 39,* 201-212.

Li, C.F., & Luh B.S. (1980). Rice snack foods. In B.S. Luh (Eds), *Rice: Production and Utilization* (pp. 690-711). Westport: Avi.

Lii, C.Y., & Chang, S.M. (1981). Characterization of red bean (Phaseolus radiatus var. aureal) starch and its noodles quality. *Journal of Food Science, 46,* 78-81.

Lii, C.Y., & Chang, Y.H. (1991). Study of starch in Taiwan. *Food Review International, 7,* 185-203.

Lu, S., Chen, C.Y., & Lip, C.Y. (1996). Gel-chromatography fractionation and thermal characterization of rice starch affected by hydrothermal treatment. *Cereal Chemistry, 73,* 5-11.

Lucisano, M., Cappa, C., Fongaro, L., Mariotti, M. (2012). Characterisation of gluten-free pasta through conventional and innovative methods: evaluation of the cooking behaviour. *Journal of Cereal Science, 56,* 667-675.

Marti, A., Seetharaman, K., & Pagani, M.A. (2010). Rice-based pasta: a comparison between conventional pasta-making and extrusion- cooking. *Journal of Cereal Science, 52,* 404-409.

Marti, A. (2010). Physical approaches to improve the quality of gluten-free pasta. PhD Dissertation, University of Milan.

Marti, A., Pagani, M.A., & Seetharaman, K. (2011a). Understanding starch organisation in gluten-free pasta from rice flour. *Carbohydrate Polymers, 84,* 1069-1084.

Marti, A., Pagani, M.A., & Seetharaman, K. (2011b). Characterizing starch structure in a gluten-free pasta by using iodine vapor as a tool. *Starch/Starke, 63,* 241-244.

Marti, A., Caramanico, R., Bottega, G., & Pagani, M.A. (2012). Effect of treatments on rice flour and coking behaviour of rice pasta. *Cereal Foods World, 57-4A*.

Mastromatteo, M., Chillo, S., Iannetti, M., Civica, V., & Del Nobile, M.A. (2011). Formulation optimisation of gluten-free functional spaghetti based on quinoa, maize and soy flours. *International Journal of Food Science & Technology, 46,* 1201-1208.

Merayo, Y. A., Gonzalez, R. J., Drago, S. L., Torres, R. L., & De Greef, D. M. (2011). Extrusion conditions and zea mays endosperm hardness affecting gluten-free spaghetti quality. *International Journal of Food Science and Technology 46,* 2321-2328.

Mestres, C., Colonna, P., & Buleon, A. (1988). Characteristics of starch networks within rice flour noodles and mungbean starch vermicelli. *Journal of Food Science, 53,* 1809-1812.

Mestres, C., Colonna, P., Alexandre, M.C., & Matencio, F. (1993). Comparison of various processes for making maize pasta. *Journal of Cereal Science, 17,* 277-290.

Nakorn. K.N., Tongdang, T., & Sirivongpaisal, P. (2009). Crystallinity and rheological properties of pregelatinized rice starches differing in amylose content. *Starch/Starke, 61,* 101-108.

Pagani, M.A. (1986). Pasta products from non-conventional raw materials. In C. Mercier, & C. Cantarelli (Eds), *Pasta and extruded products* (pp. 52-68). London: Elsevier Applied Science.

Pagani, M.A., Bonomi, F., Bottega, G., Casiraghi, M.C., Elkhalifa, A.E.O., & Iametti, S. (2010). Characterizing sorghum-based pasta: a multi-disciplinary approach. Proceedings in 2nd Second International Symposium on Gluten-Free Cereal Products and Beverages, June 8–11, Tampere, Finland.

Raina, C.S., Singh, S., Bawa, A.S., & Saxena, D.C. (2005). Textural characteristics of pasta made from rice flour supplemented with proteins and hydrocolloids. *Journal of Texture Studies, 36,* 402-420.

Resmini, P., & Pagani, M.A. (1983). Ultrastructure studies of pasta: a review. *Food Microstructure, 2,* 1-12.

Sanchez, P.C. (1975). Varietal influence on the quality of Phillipines rice. *Food Technology, 25,* 51-52.

Schoenlechner, R., Drausinger, J., Ottenschlaeger, V., Jurackova, K., & Berghofer, E. (2011). Functional properties of gluten-free pasta produced from amaranth, quinoa and buckwheat. *Plant for Foods and Human Nutrition, 65,* 339-349.

Singh, S., Raina, C.S., Bawa, A.S., & Saxena, D.C. (2004). Sweet potato-based pasta product: optimization of ingredient levels using response surface methodology. *International Journal of Food Science and Technology ,39,* 191-200.

Sozer, N. (2009). Reological properties of rice pasta dough supplemented with proteins and gums. *Food Hydrocolloids, 23,* 849-855.

Suhendro, E.L., Kunetz, C.F, McDonough, C.M., Rooney, L.W. & Waniska, R.D. (2000). Cooking characteristics and quality of noodles from food sorghum. *Cereal Chemistry, 77,* 96-100.

Tam, L.M., Corke, H, Tan, W.T., Li, J., & Collado, L.S. (2004). Production of Bihon-type noodles from maize starch differing in amylose content. *Cereal Chemistry, 81,* 475-480.

Tan, H.Z., Li, Z.G., & Tan, B. (2009). Starch noodles: history, classification, materials, processing, structure, nutrition, quality evaluating and improving. *Food Research International, 42,* 551-576.

Tester, R.F., & Debon, S.J.J. (2000). Annealing of starch - a review. *International Journal of Biological Macromolecules, 27,* 1-12.

Thompson, T. (2009). The nutritional quality of gluten-free foods. In E. Gallagher (Eds), Gluten-*free food science and technology* (pp. 42-51). Oxford: Blackwell Publishing Ltd.

Tsao, T., Beetner, G., Lorenz, K., & Frey, A. (1976). Extrusion processing of instant rice spaghetti. *Lebensmittel-Wissenschaft and Technologie, 9,* 96-98.

Vasanthan, T., & Li, J.H. (2003). Hypochlorite oxidation of field pea starch and its suitability for noodle making using an extrusion cooker. *Food Research International, 36,* 381-386.

Wang, N., Bhirud, P.R., Sosulski, F.W., & Tyler, R.T. (1999). Pasta-like product from pea flour by twin-screw extrusion. *Journal of Food Science, 64,* 671-678.

Waniska, R.D., Yi, T., Lu, J., Xue-Ping, L., Xu, W., & Lin, H. (1999). Effects of preheating temperature, moisture, and sodium metabisulfite content on quality of noodles prepared from maize flour or meal. *Food Science and Technology International, 5,* 339-346.

Wolf, B. (2010). Polysaccharide functionality through extrusion processing. *Current Opinion in Colloid and Interface Science, 15,* 50-54.

Yalcin, S., & Basman, A. (2008a). Effects of gelatinisation level, gum and transglutaminase on the quality characteristics of rice noodle. *International Journal of Food Science and Technology, 43,* 1637-1644.

Yalcin, S., & Basman, A. (2008b). Quality characteristics of corn noodles containing gelatinized starch, transglutaminase and gum. *Journal of Food Quality, 31,* 465-479.

Yoenyongbuddhagal, S., & Noomhorm, A. (2002). Effect of physicochemical properties of high-amylose thai rice flours on vermicelli quality. *Cereal Chemistry, 79,* 481-485.

Zandonadi, R.P., Botelho, R.B.A., Gandolfi, L., Ginani, J.S., Montenegro, F.M., Pratesi, R. (2012). Green banana pasta: an alternative for gluten-free diets. *Journal of the Academy of Nutrition and Dietetics, 112,* 1068-1072.

Zavareze, E. da R., Storck, C.R., de Castro, L.A.S., Schirmer, M.A., & Dias, A.R.G. (2010). Effect of heat-moisture treatment on rice starch of varying amylose content. *Food Chemistry, 121,* 358-365.