Gluten-free Pasta—Advances in Research and Commercialization

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Due to its ease of preparation, palatability, versatility, low cost, nutritional value, and long shelf life, pasta is an extremely popular commercial food product. Pasta products are commonly produced by extrusion, and their main ingredients are durum wheat semolina and water. Celiac disease is an immune-mediated disease triggered by the ingestion of the protein composite gluten. The only treatment for celiac disease is the permanent exclusion of sources of gluten (wheat, rye, and barley products) from the diet. It is important, therefore, that high-quality cereal products made from alternative grains are available to this segment of the popultion. Recently, research on the development and improvement of gluten-free pasta has intensified. At the same time, the number of gluten-free pasta products available on the market has increased dramatically.

There is some question as to whether the findings of food scientists are well reflected in available gluten-free products. This article presents an overview of the outcomes of recent studies and of the composition and quality of commercial gluten-free pasta samples. Samples of 33 pasta products sold as "gluten-free pasta" were screened in this study. The samples were sourced from eight European countries (Austria, Finland, France, Germany, Ireland, Italy, Portugal, and Sweden). For comparison, an Italian brand of wheat pasta (DeCecco) was included in the study.

Selection of Gluten-free Raw Materials

Celiac disease is a lifelong immune disorder in which parts of the small intestine are damaged or destroyed by the immune system in reaction to ingestion of gluten. Currently, the only treatment for celiac disease is a gluten-free diet. The dietary requirements of celiac patients have created a demand for products made from raw materials other than wheat, rye, and barley, all of which contain gluten. The utilization of rice (13) and corn (8,17) for the production of pasta has been well researched and are the most commonly used gluten-free ingredients in the food industry: 22 of the 33 commercial products screened in this study contained rice, and 20 of 33 products contained corn. Other less well-researched gluten-free raw materials used for pasta production include the pseudocereals quinoa (3), buckwheat (1), and amaranth (20). Of the 33 commercial products screened in this study, only 1 contained quinoa and 1 contained buckwheat. Despite the high nutritional quality of buckwheat, its use is limited due to its higher price compared with corn and rice, as well as its dark color and strong flavor. Amaranth was not found in the commercial products screened in this study. Chillo et al. (5) reported that the use of amaranth flour alone in pasta presented remarkable difficulties in the extrusion phase. However, the incorporation of quinoa, chickpea, and broad bean flour improved amaranth pasta, and the resulting products demonstrated excellent cooking performance, as well as sensory properties (6). The majority of pasta products screened in this study contained a mixture of the abovementioned gluten-free raw materials. The use of a mixture of materials balances out the sensorial deficits of single flours and helps compensate for their technological shortcomings.

Apart from gluten-free grains, noncereal sources have also been considered for the production of pasta. Some commercial pasta products contain chickpea and lupin flours, as well as potato flour. Response surface methodology was used by Singh et al. (21) to develop a formulation based on sweetpotato and soy flours. Schoenlechner et al. (20) replaced 3% of amaranth, quinoa, or buckwheat flour with egg white powder, soy protein isolate, and casein. With regard to textural characteristics and cooking loss, egg white powder was superior. Soy protein and casein addition led to products that disintegrated faster during cooking, indicating a weaker dough matrix. Chillo et al. (7) also observed a negative effect of casein on pasta quality. One of the commercial brands (Semper) screened in this study contained soy flour, while none of the commercial pastas screened contained egg products or milk proteins. Pea protein was used in two of the commercial brands (Gerblé and Schär) screened.

A satisfactory pasta product is characterized by a uniform color and smooth surface, mechanically strong strands, and low matter loss during cooking. Because these properties are often not satisfactory when using gluten-free cereals, as opposed to wheat semolina, additives such as emulsifiers may be employed. The fatty nature of emulsifiers enables them to act as a lubricant in the extrusion process, resulting in less nozzle wear and making production easier. They can also provide a firmer consistency, a less sticky surface, and better starch retention properties during cooking (13). Regarding the samples screened in this study, 39% contained mono- and diglycerides of fatty acids (E471). Several authors have reported that pregelatinization of starch-rich ingredients can improve the functional properties and provide body and texture in a product (17). Although production of pasta containing oat or quinoa flour alone failed, Chillo et al. (4) obtained acceptable results with the addition of pregelatinized starch as a structuring agent. Portions of the flours were heated to 80°C, cooled, and added to the flour-water mixture. Among the commercial products reviewed, only one (Gerblé) label stated that precooked maize flour was an ingredient. Other products screened may also contain modified starches, because starches altered by physical means or enzymes may be labeled simply as "starch" rather than with a specific name. However, this designation must be complemented by the indication of its origin if the source may contain gluten (9). Another well-researched group of ingredients, hydrocolloids, were not found in the commercial products screened. However, studies have shown that the incorporation of polysaccharides such as xanthan, carboxymethylcellulose, locust bean, or guar gum can result in pasta with improved sensory characteristics (12,18).

Challenges in Gluten-free Pasta Production

Pasta is a collective term used to describe products such as macaroni, spaghetti, lasagna sheets, and fettuccine. Its

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production involves mixing, kneading, extrusion, shaping, and drying. Although the use of rice for the formulation of noodles has been well studied, literature on the formulation of pasta from gluten-free raw materials is scarce. The main difference between noodle and pasta processing is that the traditional process for making noodles involves several heating and cooling steps aimed at reorganization of the starch matrix (14), while pasta processing consists of a simple extrusion step. Conventional wheat pasta is usually produced from durum semolina, a granular product achieved through a special grain-milling process. According to the publications reviewed, gluten-free pasta is usually made from flour rather than semolina. This can be explained by the fact that the availability of gluten-free raw materials in general is limited, as is the production of gluten-free semolina.

The significantly smaller particle size found in flour can cause thermal stresses during pasta manufacture that may cause protein denaturation (2); in addition, hydration during the mixing step is different. A mixing stage prior to extrusion allows starch and proteins to hydrate. A slightly elevated water temperature is used to speed up the mixing process. This is a particularly important step during the manufacture of pasta because incomplete and uneven hydration of flour impairs the quality of the resulting product (e.g., tendency to crack and uneven color) (2).

Semolina is usually mixed with water at an approximate ratio of 30:100 (water/semolina) (22). For the production of gluten-free pasta, water levels are usually higher. For example, Schoenlechner et al. (20) produced pasta from amaranth, quinoa, and buckwheat flours with a dough moisture of 30–35%. Dough moisture that is too high toughens the dough, which then adheres to the screw and leads to sticky pasta with low texture firmness, whereas dough moisture that is too low results in pasta with surface cracks (20). If the formulation contains additional protein or fiber ingredients, the required water level is even higher. The dough is forced at high pressure through a dye to obtain the desired pasta shape and size. The process conditions during extrusion (i.e., dough moisture and extrusion temperature) are carefully controlled. Hence, in uncooked pasta most of the starch is ungelatinized and proteins are largely undenatured.

In order to transform the relatively unstable extrudate into a convenient product with a long shelf life, a drying step is necessary. The moisture content of fresh pasta as it emerges from the die is ≈30%. During drying, the moisture content must be reduced to <12.5% in such a way that the complex protein and starch structure remains unchanged and cracking and other physical defects are avoided (2).

The production of cereal-based products from nonwheat sources presents a major technological challenge. To overcome this hurdle, researchers and product developers have focused mainly on the search for appropriate ingredients and additives suitable for the production of a cohesive structure. However, more focus should be placed on the role of processing conditions that will promote starch organization that is able to substitute for a gluten network in the final product. Marti et al. (15,16), for example, compared conventional extrusion at 50°C with extrusion cooking (115°C) and found that the latter improved the cooking quality of rice-based pasta. Cooling cycles, as utilized in rice noodle making, can lead to starch retrogradation, which in turn results in decreased stickiness and cooking loss.

Sensory and Texture Properties of Gluten-free Pasta

The two main features of pasta quality are texture and color and appearance. With regard to color and appearance it is possible to create gluten-free products that are similar to their wheat counterparts (e.g., Seitz, Roma and Tesco gluten-free pasta brands). These products appear smooth, with a glossy surface and clear, bright yellow color. However, many of the commercial products that were screened showed undesirable coloring. Products containing corn frequently were too orange, and those containing rice were often too white or even translucent. Several of the products screened were grayish, had an inhomogeneous surface, or had black spots.

Achieving texture properties in gluten-free products that are equal to those of wheat products is challenging. A high degree of firmness and elasticity, termed "al dente," is considered a sign of good quality pasta (2). This consistency is difficult to obtain when using gluten-free raw materials. Cooked gluten-free pasta is often too soft, and the mouthfeel is not comparable to wheat counterparts. Although many of the commercial samples screened had firmness values equal to or higher than the wheat pasta sample, their elastic limit was often significantly lower (Table I). The firmness of the wheat control sample was 503 g, while the gluten-free samples ranged from 149 to 1,264 g. Regarding elasticity, gluten-free samples ranged from 11 to 71 g and only 8 of 33 samples had values higher or equal to those for the wheat pasta sample (45 g).

A common problem regarding gluten-free pasta is the stickiness of the cooked product. During production of wheat pasta, a gluten layer is formed that entraps the starch granules (19). A weak or discontinuous protein matrix, as is found in gluten-free products, permits starch to leach out during the cooking process, and the resulting cooked pasta becomes sticky. Figure 1 shows commercial wheat and gluten-free spaghettis. While the wheat spaghetti shows a continuous outer layer several micrometers thick, this layer is not observed in the gluten-free sample, which results in increased cooking loss and stickiness. Stickiness values for the commercial gluten-free pasta samples varied widely from 10 to 55 g. The value for the commercial wheat pasta sample was 22.93 g. Gluten-free products tend to disintegrate during cooking, which does not allow enough cooking time to achieve a well-cooked pasta (20). Due to an insufficient cooking time, the resulting cooked pasta often has poor sensory characteristics (earthy, musty, malty, bitter, and/or germ-like flavors) and poor digestibility. Strong corn or popcorn flavors were observed for products made with high proportions of maize flour. Also, intense rice or milk rice flavors were attributed to several gluten-free samples.

Nutritional Value of Gluten-free Pastas

There are concerns that gluten-free products based on white rice, maize flour, and potato starch contain suboptimal levels of nutrients, with a higher percentage of calories being obtained from fat (23). Although the energy contents (calories) of the commercial gluten-free products screened in this study were similar or higher than in the wheat counterpart, the composition of the energy contents was different (Table II). About half the samples contained more fat than the DeCecco wheat pasta. The wheat pasta cample contained 1.5 g of fat, while the gluten-free pasta samples screened contained 0.3–3.6 g. All products had lower protein contents than the wheat counterpart (3.0–10.7 g/100 g and 13.0 g/100 g, respectively). As a result, the carbohydrate content was higher in all gluten-free samples than in the wheat counterpart (70–86 g/100 g compared with 70 g/100 g). Most of the commonly used gluten-free flours have naturally lower protein contents than their wheat counterparts (11). Therefore, the use of grains such as quinoa, buckwheat, or teff or the addition of ingredients such as pulses or milk proteins may be recommended. An obvious ingredient that can be used to increase the protein content of gluten-free pasta is eggs. Eggs are traditionally used mainly to achieve a flavor effect and can be added fresh or frozen or as dried powders (2). Soybean flours are a good source of vegetable proteins (38–40%) and, hence, have been used in several studies to improve the nutritional value of gluten-free pastas (17).

The dietary fiber content of the majority of screened gluten-free products was generally lower than in the wheat pasta counterpart (2.9 g/100 g). However, 5 of 33 gluten-free pasta products had higher fiber contents (up to 4.6 g/100 g). These contained less refined flours such as brown rice flour. None of the products contained additional fiber ingredients. Because the dietary fiber intake of the general population, especially among celiac disease patients, is often too low (10), the inclusion of nonstarch polysaccharides such as inulin, β-glucan, bamboo, or pea fiber may be recommended. Apart from the nutritional value, fiber incorporation also has an effect on texture. Its incorporation into the starch matrix has been reported to reduce extreme firmness in pasta made with white rice flour (16).

To make food labeling more useful for consumers, packaging in the United States lists daily values for each nutrient. These recommendations are shown in the bottom line of Table II. The percent contribution of 100 g of each sample considered in this study was calculated and compared. Regarding the contribution of gluten-free pasta to the daily value for protein, 100 g of each sample on average delivered only ≈13% of the daily value, with percentages ranging from as low as 6% for a maize pas-

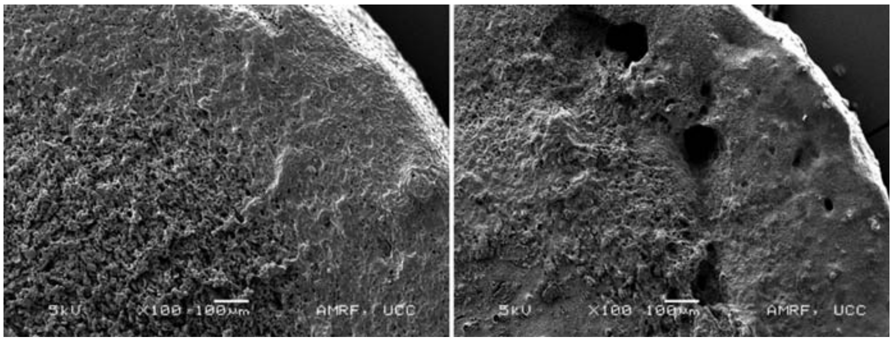

Fig. 1. Micrographs taken with a scanning electron microscope (JSM-5510, JEOL Ltd.), with a working distance of 8 mm and accelerating voltage of 5 kV at a magnification level of x100. Left, cooked commercial wheat pasta; right, cooked commercial gluten-free pasta.

Table I. Mechanical properties of wheat control and gluten-free pasta samples[a]

Brand	Product	Firmness (g)	Stickiness (g)	Elastic Limit/ Tensile Strength (g)
DeCecco	No 12 Wheat Pasta	503 ± 16	22.93 ± 7.27	45.03 ± 1.15
3 Pauly	Spaghetti, Glutenfreie Maiswaren	271 ± 92	29.30 ± 3.01	21.12 ± 1.60
Biofair	Organic Rice Spaghetti	372 ± 28	40.26 ± 2.95	30.15 ± 2.49
Biofair	Organic Rice Quinoa Spaghetti	551 ± 132	13.23 ± 2.83	36.91 ± 1.83
Bioryza	Spaghetti de Riz Sans Gluten	249 ± 30	54.27 ± 3.11	22.11 ± 1.29
Bioryza	Spaghetti de Riz Complet	515 ± 18	19.56 ± 0.95	28.64 ± 0.60
Carrefour	Spaghetti No Gluten	296 ± 17	12.49 ± 2.00	20.85 ± 1.19
DIET Radisson	Pasta de Maiz	682 ± 46	13.57 ± 2.28	59.64 ± 2.73
Doves Farm	Organic Spaghetti (Maize and Rice)	297 ± 12	37.41 ± 3.21	23.40 ± 1.61
Doves Farm	Organic Spaghetti (Brown Rice)	249 ± 47	34.27 ± 9.28	30.13 ± 2.54
Ellen's Allergy Friendly	Spaghetti Mais	554 ± 59	12.69 ± 1.31	41.54 ± 3.63
Gallo DAL 1856	3Cereali Riso, Mais, Grano Saraceno	415 ± 54	15.36 ± 2.36	26.52 ± 2.03
Gerblé	Spaghetti	166 ± 14	17.73 ± 1.69	16.26 ± 2.16
Glutano	Spaghetti Glutenfrei	476 ± 27	13.30 ± 1.78	29.46 ± 0.53
Hammermühle	Spaghetti (Lupinus)	403 ± 47	13.13 ± 1.22	24.02 ± 2.07
Hammermühle	Spaghetti (Chickpea)	541 ± 64	12.73 ± 1.22	32.18 ± 2.92
Kelkin	Gluten-free Spaghetti	742 ± 31	16.10 ± 2.41	47.27 ± 1.19
Le Veneziane	Gli Spaghetti	1,019 ± 58	11.50 ± 0.71	54.87 ± 2.40
Moilas	Wholemeal Rice Spaghetti	210 ± 12	37.13 ± 3.58	19.36 ± 0.70
Organ	Gluten-free Corn and Rice Spaghetti	746 ± 61	15.51 ± 2.17	71.26 ± 4.47
Primeal	Spaghetti Mais & Riz	149 ± 23	20.81 ± 1.16	10.59 ± 1.10
Probios	Rice&Rice	772 ± 81	35.25 ± 5.91	42.95 ± 6.17
Probios	Viva Mais	1,264 ± 121	12.54 ± 1.93	55.60 ± 4.94
Rapunzel	Reis-Spaghetti	464 ± 33	14.29 ± 1.17	49.81 ± 1.00
Riso Scotti	Pasta Riso, Spaghetti	518 ± 53	12.38 ± 0.85	37.77 ± 1.67
Rizopia	Organic Brown Rice Pasta Spaghetti	623 ± 60	38.75 ± 9.11	45.06 ± 8.82
Roma	Gluten-free Spaghetti	151 ± 14	13.79 ± 1.77	23.04 ± 1.13
Sam Mills	Pasta d'Oro	963 ± 197	15.63 ± 2.39	35.50 ± 2.73
Schär	Spaghetti, Naturally Gluten Free	789 ± 31	10.02 ± 0.13	70.31 ± 3.49
Seitz	Glutenfrei Spaghetti (Maize and Chickpea)	433 ± 44	12.97 ± 0.61	23.76 ± 0.43
Semper	Spaghetti	288 ± 45	14.19 ± 0.47	27.74 ± 2.68
SPAR free from	Spaghetti	298 ± 40	21.92 ± 0.75	19.82 ± 0.38
Tesco	Free From Spaghetti	188 ± 16	19.45 ± 1.20	21.26 ± 2.13
Tinkyada	Pasta Joy Ready	200 ± 12	18.88 ± 1.17	27.44 ± 1.88

[a] Determined using a texture analyzer system (TA.XT2i, Stable Micro Systems) and AACC International Approved Method 66-50.01 (AACC 1999).

ta product up to 21% for quinoa spaghetti, while 100 g of the wheat pasta counterpart contributed to 26% of the daily value. Because pasta is generally low in fat, 100 g of the commercial wheat pasta sample contained 2.5% of the daily value. However, 100 g of gluten-free spaghetti contained up to 4.6%. The contribution of the wheat pasta sample to the daily value for total carbohydrates was lower than that of the gluten-free samples (23% compared with 23–29%). The majority of gluten-free samples contributed to the daily dietary fiber value to a much lower extent than did the wheat pasta sample (11%). However, products made from brown rice contained up to 18% of the daily fiber value.

Conclusions

Literature on the optimization of gluten-free pasta is scarce. Further research should be performed, especially to determine optimal processing conditions. The gluten-free pasta products offered on the market should be improved in terms of color, matter loss during cooking, and stickiness, as well as elasticity. Regarding nutritional value, the protein and fiber contents of gluten-free pastas should be increased. Finally, better synergistic cooperation between research centers and the food industry would enable a beneficial knowledge-transfer process and facilitate the production of high-quality gluten-free pasta in terms of texture, sensory, and nutritional properties.

Table II. Nutritional values for wheat control and gluten-free pastas as stated on the product packaging

					Carbohydrates		Fats			
Brand	Product	Country of Purchase	Energy (kcal/100 g)	Protein (g/100 g)	Total (g/100 g)	Sugars (g/100 g)	Total (g/100 g)	Saturated (g/100 g)	Dietary Fiber (g/100 g)	Sodium (g/100 g)
DeCecco	No 12 Wheat Pasta	Italy	352	13	70.2	3.4	1.5	0.3	2.9	0.004
3 Pauly	Spaghetti, Glutenfreie Maiswaren	Germany	366	3.0	85	0.5	1.6	0.3	2.8	<0.02
Biofair	Organic Rice Spaghetti	Ireland	384	6.9	85		0.5			
Biofair	Organic Rice Quinoa Spaghetti	Ireland	369	10.7	75		0.7			
Bioryza	Spaghetti de Riz Complet	France	345	8.3	71.5		2.8		4.6	
Bioryza	Spaghetti de Riz Sans Gluten	France	365	7.5	76.5		3			
Carrefour	Spaghetti No Gluten	France	357	6.7	79	0.2	1.3	0.5	1.1	0.001
DIET Radisson	Pasta de Maiz	Portugal	358	7.5	79	0.5	1.3	0.6	1.6	0
Doves Farm	Organic Spaghetti (Maize and Rice)	Ireland	347	7.0	76	0.4	0.9	Trace	2.4	Trace
Doves Farm	Organic Spaghetti (Brown Rice)	Ireland	338	7.9	70.3	0.5	1.5	Trace	4.1	Trace
Ellen's Allergy Friendly	Spaghetti Mais	Italy	358	7.5	77	0.7	1.8	0.4	1.7	<0.02
Gallo DAL 1856	3Cereali Riso, Mais, Grano Saraceno	Italy	353	7.0	77	0.5	1.6	0.4	1.4	0.0019
Gerblé	Spaghetti	France	365	7.3	79.2	0.2	2.1	1.1	1.3	0.1
Glutano	Spaghetti Glutenfrei	Finland	359	6.4	78.4		2.2			
Hammermühle	Spaghetti (Chickpea)	Germany	370	3.3	86		1			
Hammermühle	Spaghetti (Lupinus)	Germany	358	3.9	82		1.6			
Kelkin	Gluten-free Spaghetti	Ireland	356	6.5	78.5	0.5	1.5	0.5	1.2	0
Le Veneziane	Gli Spaghetti	Italy	345	7.8	77.8		0.71			
Moilas	Wholemeal Rice Spaghetti	Finland	339	7.9	70.3	0.5	2.1	0.4	4.1	
Organ	Gluten-free Corn and Rice Spaghetti	Italy	348	5.6	79.8	0.9	0.9	0	2.7	0.01
Primeal	Spaghetti Mais & Riz	France	340	7.0	76		0.9			
Probios	Viva Mais	Finland	358	7.5	79	0.5	1.3	0.6	1.6	0.0012
Probios	Rice&Rice	Finland	345	7.0	79	0.9	0.3	0.1	2.5	0.0011
Rapunzel	Reis-Spaghetti	Germany	351	7.1	79		0.6			
Riso Scotti	Pasta Riso, Spaghetti	Italy	360	6.2	80.6		1.4			
Rizopia	Organic Brown Rice Pasta Spaghetti	Ireland	360	7.9	76.8	0.6	2.4	0.4	3.2	
Roma	Gluten-free Spaghetti	Ireland	355	7.0	78.4	0.5	1	0.2	2	0.03
Sam Mills	Pasta d'Oro	Germany	350	8.0	72	3.5	1.1	0	3.5	<0.001
Schär	Spaghetti, Naturally Gluten Free	Italy	358	9.0	73.7		2.5			
Seitz	Glutenfrei Spaghetti (Maize and Chickpea)	Germany	371	5.2	81	<0.5	2.4	0.6	2.1	0.002
Semper	Spaghetti	Sweden	350	8.5	76	0.7	1.8	1	3	0.01
SPAR free from	Spaghetti	Austria	348	5.9	76.7	0.2	1.5	0.5	2.2	0.001
Tesco	Free From spaghetti	Ireland	355	7.0	78.4	0.5	1.0	0.2	0.2	Trace
Tinkyada	Pasta Joy Ready	Ireland	375	7.14	76.8	0	3.6	0.89	3.57	0.027
Daily values[a]			2,000	50	300		<65	<20	25	<2.4

[a] Based on a 2,000 calorie diet. U.S. Food and Drug Administration. Title 21: Food and Drugs § 101.9, Nutrition Labeling of Food. In: *Code of Federal Regulations* (http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=%2Findex.tpl).

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