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Application of Inulin in Pasta: The Influence on Technological and Nutritional Properties and on Human Health—A Review †

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Abstract: Inulin is a molecule, namely, a functional dietary fiber from non-digestible carbohydrates, and is generally utilized in pasta production at concentrations or replacement ratios of 0.5–20%. As highlighted in this study, the optimum cooking time and swelling index of inulin-added pasta ranged between 5.0–14.0 min and 1.5–2.6 g/g, respectively. The protein content generally decreased, whereas dietary fiber increased with the addition of inulin to pasta formulations. Therefore, lower starch hydrolysis and glycemic index could be achieved with inulin enrichment in pasta. However, more in vitro and in vivo digestion studies are still needed to evaluate its beneficial effects on human health.

Keywords: Jerusalem artichoke; chicory; degree of polymerization; prebiotic; texture; glycemic index

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1. Introduction

Inulin fructans are principally linear molecules including predominantly β-(2-1) fructosyl-fructose links and typically have a terminating glucose molecule [1]. They are a naturally soluble dietary fiber and are regarded as a non-digestible carbohydrate of fructan due to having characteristic β-(2-1) glycosidic linkages [2]. They can be extracted from several plants, particularly tubers of Jerusalem artichoke (*Helianthus tuberosus*), dahlia (*Dahlia pinnata*), the roots of chicory (*Cichorium intybus*), and yacon (*Polymnia sonchifolia*), for commercialization [3]. Apart from possessing prebiotic properties that positively affect the activity and/or composition of gut microbiota that confer a benefit on host health [1], thus having a gastrointestinal protective activity, they also show hypoglycemic, hepato-protective, immunomodulatory, and antitumor activities, according to the results of much human- and animal-based experimental research [2]. Therefore, inulin is accepted as a molecule, namely, a functional dietary fiber from non-digestible carbohydrates.

Inulin's degree of polymerization (DP), which is a determinant for both its functional and nutritional properties, is in the range of 10–65 and is influenced by several factors such as species, cultivar, age, and harvest time of the plant and also by the process methods and parameters of extraction [1]. Inulin is generally utilized in food products for many different purposes, such as fat replacement, sugar replacement, and texture/viscosity modification, due to its techno-functional properties and it being a source of prebiotic and dietary fiber sources. Therefore, it has wide use, mainly in baked goods (bread, cake, breakfast cereals, etc.), dairy products (cheese, yoghurt, ice cream, etc.), juices, and even sausages [4]. On the other side, over the last two decades, inulin has also been utilized at concentrations from 0.5% to 20% in pasta/noodle production, particularly in the spaghetti form (Tables 1 and 2), generally using a manual sheeting machine or a pasta maker as the single-screw extruder with/without vacuum conditions. Therefore, several studies have evaluated the effect of extracted or commercial inulin with different DP on the technological and nutritional properties of pasta, as seen in Tables 1 and 2, respectively. However, there is still a limited amount of research that has assessed the possibility of using inulin in gluten-free pasta production [5,6], as far as we know. In one study, maize flour-based gluten-free pasta samples were enriched with inulin from 5% to 20% [5]. Although an increase in inulin concentration adversely influenced the sensorial attributes (color, firmness, and taste) of cooked gluten-free pasta samples, the overall quality was above the acceptability threshold [5]. In another study, inulin was proposed for enrichment as a dietary fiber for gluten-free instant pasta formulations based on a mixture of rice flour, buckwheat flour, and soy flour [6]. In this regard, the addition of 1–5% of inulin did not negatively influence dough sheeting, but a problem with fragility occurred with the addition of inulin at higher levels [6].

Table 1. The major effects of using inulin on the technological properties of pasta.

Inulin Type, Properties, and Usage Ratio	Pasta Shape/Type	Major Findings In Technological Properties	References
Commercial (ND): 4% [a]	Turkish noodle	Moisture↑, volume increase↑, CT↓, WA↑, CL↓, Color(Raw): L*↑, a*↓, b*↑; Color(Cooked): L*↓, a*↑, b*↑, Texture(Raw): firmness↑, total shearing force↑; Texture(Cooked): hardness↔, adhesiveness↑, Sensory(Raw): color↓ˆ, apperance↔ˆ, fragility↑ˆ; Sensory(Cooked): color↑ˆ, hardness↓ˆ, chewability↓ˆ, taste↓ˆ	[7]
Commercial (average DP ≥ 23): 5 [a] and 10% [a]	–	CT↓ˆ, SI↓ˆ, CL↑ˆ, Color(Raw): L*↑, a*↓, b*↑, Texture(Cooked): firmness↓ˆ(5%), ↑ˆ(10%)	[8]
Commercial (average DP ≥ 23): 0.5%	Gluten-free noodle	Diameter↑, extrusion force↔, CT↑, WA↑, SI↑, CL↓, Color(Raw): L*↓, a*↔, b*↓; Color(Cooked): L*↑, a*↑, b*↑, Texture(Raw): firmness↑, work of shear↑, hardness↓, adhesiveness↓, chewiness↑, resilience↑; Texture(Cooked): firmness↑, work of shear↔, hardness↔, adhesiveness↑, chewiness↓, resilience↔	[9] [b]
Extracted from artichoke roots: 5 [a], 10 [a], and 15% [a]	Fresh tagliatelle	Moisture↓(except 15%), CT↑ˆ, WA↔, SI↓, CL↑, Color(Raw): L*↓, a*↑, b*↓, Color(Cooked): L*↓, a*↑, b*↓, Texture(Raw): firmness↑, Texture(Cooked): firmness↑, Sensory: color↑, firmness, bulkiness↔, adhesiveness↔, odor, taste↓	[10]
Extracted from cardoon roots (H-DP), commercial (L-DP= average DP: 20–25): 2 and 4%	–	CT↓ˆ, SI: ↓(L-DP); ↑(H-DP), WA: ↓(L-DP); ↔(2% H-DP), ↑(4% H-DP), CL↑, Texture(Cooked): hardness↓, adhesiveness↑(except 2% H-DP), Sensory(Dried): color↔, break to resistance↔, overall quality↔; Sensory(Cooked): color↔, firmness↓, elasticity↔, bulkiness↓, adhesiveness↓, taste↔, overall quality↓ (except 4% H-DP)	[11]
Commercial (average DP ≥ 10, average DP ≥ 23): 15% [a]	–	Moisture↑, CT↑ˆ, WA↑, SI↑, CL↑, Color(Raw): L*↓, a*↑(DP ≥ 10), a*↔(DP ≥ 23), b*↓(DP ≥ 10), b*↔ (DP ≥ 23); Color(Cooked): L*↑, a*↑, b*↓, Texture(Cooked): firmness↓(DP ≥ 10); ↔(DP ≥ 23), maximal breaking strength: ↓(DP ≥ 10); ↔(DP ≥ 23)	[12]
Commercial (H-DP: average DP: 8–13), commercial (L-DP= average DP: 7-8): 2.5 [a], 5 [a], 7.5 [a], 10 [a], and 20% [a]	Spaghetti	CT↑ˆ(2.5%, 5% H-DP); ↓ˆ(7.5, 10, 20% H-DP; 5, 7.5, 10% L-DP), WA↔ (7.5, 10, 20% H-DP); ↓(except 2.5% L-DP), SI↔(2.5, 20%H-DP; 2.5, 5% L-DP); ↓(7.5, 10% H-DP and L-DP), CL↑, Texture(Cooked): firmness↔ (2.5% L-DP; except 20% H-DP); ↓(5, 7.5, 10% L-DP), Sensory: firmness↓(except 2.5 L-DP),chewy↓ (except 2.5% L-DP), rubbery↓ (except 2.5% L-DP), roughness↑ (2.5, 5, 7.5, 10% L-DP)	[13]
Commercial (average DP: ≈8–13): 2.5, 5, 7.5, and 10%	–	Dry matter↑, WA↓ˆ, SI↓, CL↔, Texture(Cooked): firmness↓ˆ, adhesiveness↔, elasticity↓(except 5%)	[14]
Commercial (average DP ≥ 23): 2.5, 5, 7.5, and 10%	–	WA↓, SI↓, CL↑, Color(Cooked): L*↑, a*↔(except 2.5%), b*↓, Texture(Cooked): hardness↓, chewiness↓, springiness: ↔(2.5%, 5%); ↓ (7.5%, 10%), cohesiveness↔	[15]
Commercial (average DP > 20): 5 [a], 10 [a], and 15% [a]	Macaroni	Moisture(Dried)↑ˆ(except 5%)	[16]

Table 1. *Cont.*

Inulin Type, Properties, and Usage Ratio	Pasta Shape/Type	Major Findings In Technological Properties	References
Commercial (average DP: 8–13): 7.5 [a], 10 [a], 12.5 [a], and 15% [a]	Spaghetti	Dry matter(raw)↑, dry matter(cooked): ↓(7.5 and 10%); ↔(12.5%); ↑(15%), SI: ↑(7.5 and 10%); ↔(12.5%), ↓(15%), CL↑, Texture(Cooked): firmness (peak force)↔, adhesiveness↑(except 7.5%), stickiness: ↓(7.5 and 10%); ↑(12.5 and 15%), elasticity↓, DSC: T_{onset}↑ˆ(except 15%), T_{endset}↑ˆ, enthalpy↓, gelatinization temperature↔ (except 15%)	[17]
Commercial (average DP≥10, DP≥23): 15% [a]	Spaghetti	Moisture↓, CL↑, Color(Raw): *L**: ↓(DP ≥ 10),; ↔(DP ≥ 23), *a**↓, *b**↓, Texture(Cooked): firmness↓, stickness↑	[18]
Commercial (average DP: 8–13): 2.5 [a], 5 [a], 7.5 [a], and 10% [a]	Spaghetti	SI↓ˆ, CL↑ˆ, Texture(Cooked): firmness↓ˆ, stickiness↑ˆ, adhesiveness↑ˆ, elasticity↓ˆ	[19]
Commercial (average DP ≥ 23): 10 [a] and 20% [a]	Spaghetti	Color: *L**↑, *a**↓, *b**↑, Texture: hardness: ↔(10%); ↓(20%), adhesiveness↓, work of shear↓	[20]
Commercial (average DP ≥ 23): 5 [a], 10 [a], and 20% [a]	–	Color(Cooked): *L*↔, *a**↔, *b**↔, Texture(Cooked): hardness↓, adhesiveness↑, work of shear↓	[21]
Extracted from Jerusalem artichoke tubers: 1, 2, and 3%	–	Color: *L**↓ˆ, *a**↑ˆ, *b**↑ˆ, Texture: hardness↑ˆ, cohesiveness↓ˆ, springiness↔ˆ	[22]

↓ indicates increase is statistically different, ↑ indicates decrease is statistically different, ↔ indicates increment or decrease is not statistically different, ˆ indicates results were not given statistically, a: concentration was given as a flour replacement ratio, b: in the case of constant hydration. CL: cooking loss, CT: cooking time, H-DP: high polymerization degree, L-DP: low polymerization degree; ND: not defined, SI: swelling index, WA: water absorption.

Table 2. The major effects of using inulin on the nutritional properties of pasta.

Inulin Type, Properties, and Usage Ratio	Pasta Shape/Type	Major Findings In Technological Properties	References
Commercial (ND): 4% [a]	Turkish noodle	Ash↑, dietary fiber↑	[7]
Extracted from artichoke roots: 5 [a], 10 [a], and 15% [a]	Fresh tagliatelle	Protein↓, lipid↓, carbohydrate↓ (except 5%), total dietary fiber↑, ash↑(except 5%), predicted glycemic index↓	[10]
Extracted from cardoon roots (H-DP), Ccommercial (L-DP = average DP: 20–25): 2 and 4%	–	Protein↓(except 2% H-DP), lipid↑ (except 4% L-DP), available carbohydrate↓, total dietary fiber↑, soluble dietary fiber↑, insoluble dietary fiber↑, starch digestibility↓	[11]
Commercial (average DP: ≈8–13): 2.5, 5, 7.5, and 10%	–	Glycemic index↔	[14]
Commercial (average DP > 20): 5 [a], 10 [a], and 15% [a]	Macaroni	Protein↓ˆ, starch↓ˆ, ash↓ˆ(except 10%)	[16]
Commercial (average DP: 8–1): 2.5 [a], 5 [a], 7.5 [a], and 10% [a]	Spaghetti	Protein↓ˆ, carbohydrate↓ˆ, starch↓ˆ, total non-starch polysaccharide↑ˆ	[19]
Commercial (average DP ≥ 23): 10 [a] and 20% [a]	Spaghetti	Protein↓, lipid↓, sugar↓, starch↓, cellulose↑, ω-3 fatty acids content↔, total dietary fiber↑	[20]
Commercial (average DP ≥ 23): 5 [a], 10 [a], and 20%	–	Protein↓(except 5%), lipid↓, sugar↑, starch↓, cellulose↑, dietary fiber↑, non-digestible carbohydrates↑, energy↓ˆ	[21]

↓ indicates increment is statistically different, ↑ indicates decrease is statistically different, ↔ indicates increment or decrease is not statistically different, ˆ indicates results were not given statistically, a: concentration was given as a flour replacement ratio. CL: cooking loss, CT: cooking time, H-DP: high polymerization degree, L-DP: low polymerization degree; ND: not defined SI: swelling index, WA: water absorption.

2. Influence of Inulin on Technological and Nutritional Properties of Pasta and Human Health

2.1. Technological Properties

The effect on major technological properties of adding inulin to pasta in terms of cooking time, swelling index, water absorption, cooking loss, color, texture, and sensorial attributes were evaluated and summarized in Table 1. The moisture content generally increased with the inclusion of inulin in pasta formulations, and this increase was generally more prominent with an increase in inulin level (Table 1). This was attributed to the typical water absorption ability of dietary fiber [7]. The optimum cooking time of inulin-enriched pasta samples was approximately in the range of 5.0–14.0 min [7–13] which is generally high compared to the control pasta without inulin [8–10,12,13]. Contrary to this, a reduction in the cooking time with inulin added to pasta has been recorded in previous studies [7,11], which could be attributed to the disruption of the gluten network resulting in easier penetration of water into starch granules. Moreover, the different cooking time values of pasta with inulin could be explained by the inulin type and its intrinsic attributes, which affect its interaction with other compounds, and also the different process parameters of pasta production [10]. On the other side, the water absorption generally increased with the inclusion of inulin in comparison with the control group [7,9,12], which did not accord with some other studies [14,15]. The swelling index values of inulin-added pasta samples were between 1.5 and 2.6 g/g [8–14,16]. The reduction in the swelling index of inulin-fortified pasta compared to the control pasta with no inulin [8,10,15] could be associated with the encapsulation of starch into reticules of dietary fiber which leads to protein and starch molecules competing for water absorption, restricting the penetration of water into starch molecules and thus limiting their swelling [10]. On the contrary, the increase in the swelling properties in pasta, including the inulin and control pasta [9,12], could be due to both the greater capacity of dietary fibers to absorb and retain water in the network composed of protein, starch, and polysaccharide [12]. The cooking loss is closely interrelated with the strength of the protein–starch matrix [7]. Although the cooking loss should not be more than 7–8% in pasta that is of a good quality [7], higher values were obtained [8,9,12,14]. In contrast with the control samples, a reduction in the firmness/hardness of pasta enriched with inulin was determined, [11,12,14,15,18,19,21], which could be ascribed to an increase in the moisture content and swelling index [12]. Conversely, an increase in the corresponding values was observed [10,22], probably due to the higher water absorption speed of dietary fibers than starch which eventuates in a firmer texture [7]. The taste value, one of the major sensorial features [7], was negatively affected in cooked pasta enriched with inulin in comparison to the control pasta samples [7,10]. In other respects, no significant differences with the control group were observed in some sensory properties such as the appearance of raw pasta [7], the color, elasticity, taste [11], bulkiness, and adhesiveness of cooked pasta [10] and also the color, break to resistance and overall quality of dried pasta [11], due to the addition of inulin (Table 1).

2.2. Nutritional Properties and Human Health

From a nutritional point of view, the protein contents generally decreased in inulin-enriched pasta [10,11,16,19–21], as shown in Table 2, which can be attributed to an increase in dietary fiber content [10]. Moreover, as expected, dietary fiber values showed an increase with a rise in inulin concentration in pasta formulations and are between the range of 3.5 and 16% [7,10,11,20,21]. Therefore, they have the potential to be labeled as "high fiber content" or a "source of fiber" in the food market [10]. The rise in dietary fiber content in pasta by adding inulin induced lower starch hydrolysis and reduced predicted glycemic index (pGI) [10]. However, in another study, the pGI values of inulin-enriched pasta irrespective of DP based on different durum wheat cultivars (Senatore Cappelli, Margherito, and Russello) did not significantly differ from the control pasta [23]. In a similar vein, no significant differences were observed in the pGI values of pasta with the addition of inulin at different concentrations (2.5–10%). However, values with a decrease in

GI from the control pasta were increased from 2.3% to 15% with rising inulin amounts [14]. On the other hand, the decrease in starch digestibility was more prominent in pasta samples including H-DP inulin than with respect to those of L-DP [11]. In another study, the highest sugar release at 20 min was detected in inulin-enriched pasta samples compared to pasta with different dietary fibers such as commercial β-glucan concentrates and psyllium, but similar values with the control group were achieved at 60 and 120 min of digestion [18].

With respect to human health, significantly lower in vivo postprandial glucose levels (90 min and 120 min after a meal) were obtained, and the glycemic index was nearly 70% in inulin-enriched protein pasta for the dietary management of chronic kidney disease in patients with type 2 diabetes ($n = 14$) [24]. In another study, while there were no significant differences in total cholesterol, HDL-cholesterol, triglycerides, and blood glucose, the total weight loss and the level of insulin and HbA1c after glucose intake were reduced in obese subjects ($n = 30$) who adhered to a low-calorie diet which included 2% chicory inulin-enriched pasta [25]. On the other side, while many soluble dietary fibers (β-glucan, arabinoxylan, fructooligosaccharides, galactose oligosaccharides, xylooligosaccharides, and arabinogalactan) significantly increased protein hydrolysis of multigrain noodles throughout gastrointestinal digestion, and thus protein digestion for school-age children, inulin could not [26].

3. Conclusions

As a consequence, inulin has a great potential as a functional dietary fiber in pasta production. However, more studies are still needed to assess clinical trials for proving its health-beneficial effects for some patients and also the in vitro and in vivo starch digestibility of inulin-added pasta from a nutritional point of view. In this regard, the synbiotic potential of inulin-added pasta formulations with different probiotics should also be evaluated. On the other side, future studies should not only deal with the optimization of inulin extraction from different plants, but also the process parameters of pasta production such as extrusion and drying for the commercialization potential of inulin-enriched pasta. Therefore, the effect of low- and high-temperature drying procedures on inulin-based pasta should be examined from a technological perspective. Moreover, there is still limited data available on the use of inulin in gluten-free pasta formulations. Additionally, it is necessary to deeply investigate the interaction of inulin and pasta ingredients, particularly starch obtained from different sources, for assisting the enlargement of inulin usage in other food products. To sum up, inulin will still take the attention of researchers and the food industry in the following years, specifically in regards to its the nutritional, technological, and human health aspects.

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