biology and life sciences forum

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Proceeding Paper

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

Gamze Nil Yazici *, Isilay Yilmaz [‡], Tansu Taspinar and Mehmet Sertac Ozer

Department of Food Engineering, Faculty of Engineering, Cukurova University, 01250 Adana, Turkey; isilayyyilmazz@gmail.com (I.Y.); ttaspinar@cu.edu.tr (T.T.); msozer@cu.edu.tr (M.S.O.)
* Correspondence: gnboran@cu.edu.tr
† Presented at the 4th International Electronic Conference on Foods, 15–30 October 2023; Available online: https://foods2023.sciforum.net/.
‡ Decreased author.

Abstract: Inulin, is a molecule namely a functional dietary fiber from non-digestible carbohydrate-based, and was generally utilized in pasta formulations at concentrations or replacement ratios of 0.5%–20%. The optimum cooking time and swelling index of inulin-added pasta were nearly range between 5.0–14.0 min and 1.5–2.6 g/g, respectively. The protein content was generally decreased, whereas dietary fiber was 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, there is still needed more in vitro and in vivo digestion studies to evaluate its beneficial effects on human health.

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

Citation: Yazici, G.N.; Yilmaz, I.; Taspinar, T.; Ozer, M.S. Application of Inulin in Pasta: The Influence on Technological, Nutritional Properties, and Human Health—A Review. *Biol. Life Sci. Forum* **2023**, *26*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Published: date

1. Introduction

Inulin fructans are principally linear molecules including predominantly β-(2-1) fructosyl-fructose links and have typically 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 could be extracted from several plants particularly tubers of Jerusalem artichoke (*Helianthus tuberosus*), dahlia (*Dahlia pinnata*), 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 for host health [1], and thus having a gastrointestinal protective activity, they also show hypoglycemic, hepatoprotective, immunomodulatory, and antitumor activities according to results of many humans, and animal-based experimental researches [2]. Therefore, inulin is accepted as a molecule namely a functional dietary fiber from non-digestible carbohydrate-based.

The inulin's degree of polymerization (DP) which is a determinant for both its functional and nutritional properties is in the range of 10–65 influenced by several factors such as species, cultivar, age, and harvest time of the plant, and also 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 being a source of prebiotic and dietary fiber sources. Therefore it has a wide usage area majorly based on bakery goods (bread, cake, breakfast cereals, etc.) and dairy products (cheese, yoghurt, ice cream, etc.), juices, and even sausages [4]. On the other side, over the last two decades, inulin is also been utilized at concentrations from 0.5% to 20% in pasta/noodle production, particularly in a spaghetti form, (Tables 1 and 2), by using the manual sheeting machine or pasta maker generally as a single screw extruder with/without vacuum conditions. Therefore, several studies evaluated the effect of the extracted or commercial inulin with different DP on the technological and nutritional properties of pasta, as seen in Table 1 and Table 2, respectively. However, there is still limited research that assessed the possibility of using inulin in gluten-free pasta production [5,6], as far as we know. In a study, maize flour-based gluten-free pasta samples were enriched with inulin from 5% to 20% [5]. Although the 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 of the gluten-free instant pasta formulation 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 the fragility problem occurred with the addition of inulin at higher levels [6].

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

2.1. Technological Properties

The effect of inulin addition to pasta on major technological properties 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 was generally increased with the inclusion of inulin in pasta formulation, and this increase is 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 could be approximately in the range of 5.0–14.0 min [7–13] which is generally higher when compared to control pasta without inulin [8–10,12,13]. Contrary to this, the reduction of the cooking time with inulin addition to pasta was also recorded in previous studies [7,11], which could be attributed to the disruption of the gluten network resulting in more easy water penetration into starch granules. Moreover, the different cooking time values of pasta with inulin could be explained by inulin type and its intrinsic attributes which affect the interaction with other compounds, and also different process parameters of pasta production [10]. On the other side, the water absorption was generally increased with the inclusion of inulin in comparison with the control group [7,9,12], which did not agree with some other studies [14,15]. The swelling index values of inulin-added pasta samples were nearly in the between 1.5–2.6 g/g [8–14,16]. The reduction in swelling index of inulin-fortified pasta when compared to control pasta with no inulin [8,10,15], could be associated with encapsulated starch with reticule of dietary fiber which led to competition of water absorption with protein and starch molecules, and restricting the water penetration to the starch and thus their swelling [10]. On the contrary, the increase in swelling properties in pasta including inulin to control pasta [9,12], could be referred to as both higher absorbing and retaining of water capacity of dietary fibers in the network composed of protein, starch, and polysaccharide [12]. The cooking loss is closely interrelated with the strength of the protein-starch [7]. Although the cooking loss should not be more than 7–8% in pasta with good quality [7], higher values were obtained [8,9,12,14,18]. In contrast with control samples, the reduction in firmness/hardness of pasta by inulin addition was determined, [11,12,14,15,18,19,21,27,28], which could be ascribed to an increase in moisture content and swelling index [12]. Conversely, the increase in the corresponding values was observed [10,22], probably due to the higher water absorption speed of dietary fiber than starch which eventuates in firmer texture [7]. The taste values as one of the major sensorial features [7], were negatively affected in cooked pasta with inulin addition in comparison to 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], color, elasticity, taste [11], bulkiness, and adhesiveness of cooked pasta [10], and also color, break to resistance and overall quality of dried pasta [11], due to inulin addition (Table 1).

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↓^, apperance↔^, fragility↑^; Sensory(Cooked): color↑^, hardness↓^, chewability↓^, taste↓^	[7]
Commercial (average DP ≥ 23): 5 [a] and 10% [a]	–	CT↓^, SI↓^, CL↑^, Color(Raw): *L**↑, *a**↓, *b**↑, Texture(Cooked): firmness: ↓^(5%), ↑^(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↑^, WA↔, SI↓, CL↑, Color(Raw): *L**↓, *a**↑, *b**↓, Color(Cooked): *L**↓, *a**↑, *b**↓, Texture(Raw): firmness↑, Texture(Cooked): firmness↑, Sensory: color↑, firmness, bulkiness↔, adhesiveness↔, odour, taste↓	[10]
Extracted from cardoon roots (H-DP), Commercial (L-DP= average DP: 20–25): 2 and 4%	–	CT↓^, 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↑^, 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 (average DP: ≈8–13): 2.5, 5, 7.5, and 10%	–	Dry matter↑, WA↓^, SI↓, CL↔, Texture(Cooked): firmness↓^, adhesivenes↔, 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)↑^(except 5%)	[16]
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}↑^(except15%), T_{endset}↑^, 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: 8–1): 2.5 [a], 5 [a], 7.5 [a], and 10% [a]	Spaghetti	SI↓^, CL↑^, Texture(Cooked): firmness↓^, stickiness↑^, adhesiveness↑^, elasticity↓^	[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**↓^, *a**↑^, *b**↑^, Texture: hardness↑^, cohesiveness↓^, springiness↔^	[22]

Commercial (average DP > 10): 5 [a], 10 [a], and 20% [a]	–	Color: L↔, a*↔, b*↔, Texture(Cooked): hardness↓, adhesiveness↑, work of shear↓	[27]
Commercial (average DP ≥ 23): 5 and 10%	–	Color: L*: ↔(5%); ↑(10%), b*↑, Texture(Cooked): hardness↓, adhesiveness↑, toughness↓	[28] [c]

↓ indicates increment is statistically different, ↑ indicates decrease is statistically different, ↔ indicates increment or decrease is not statistically different, ^ Results were not given statistically, a: concentration was given as a flour replacement ratio, b: in the case of constant hydration, c: in the case of eggless pasta, 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.

2.2. Nutritional Properties and Human Health

According to a nutritional point of view, the protein contents are generally decreased in inulin-enriched pasta [10,11,16,19–21,27,28], as given in Table 2, which is 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 about 3.5–16% [7,10,11,20,21]. Therefore they have the potential to be labeled as "high fiber content" or "source of fiber" in the food market [10]. The rise in dietary fiber content in pasta by adding inulin induced lower starch hydrolysis and 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 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 of decrease in GI from control were increased from 2.3% to 15% with rising inulin amount [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 as 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].

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 Nutritional 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), Commercial (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↓^, starch↓^, ash↓^(except 10%)	[16]
Commercial (average DP: 8–1): 2.5 [a], 5 [a], 7.5 [a], and 10% [a]	Spaghetti	Protein↓^, carbohydrate↓^, starch↓^, total non-starch polysaccharide↑^	[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↓^	[21]
Commercial (average DP > 10): 5 [a], 10 [a], and 20% [a]	–	Protein↓(except 5%), lipid↓, sugar↑, starch↓, cellulose↑, dietary fiber↑, non-digestible carbohydrates↑, energy↓^	[27]

Commercial (average DP ≥ 23): 5 and 10%	–	Protein↓, lipid↔, sugar↑, starch↓, cellulose↑	[28] [c]

↓ indicates increment is statistically different, ↑ indicates decrease is statistically different, ↔ indicates increment or decrease is not statistically different, ^ 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.

In respect to the human health perspective, significantly lower in vivo postprandial glucose levels (90 min and 120 min after 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 load was reduced in obese subjects (n = 30) adherent to the low-calories 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 great potential as a functional dietary fiber in pasta production. However, more studies are still needed to assess clinical trials for proving health-beneficial effects for some patients and also in vitro and in vivo starch digestibility of inulin-added pasta from the nutritional point of view. In this regard, the synbiotic potential in inulin-added pasta formulations with different probiotics should also be evaluated. On the other side, the following studies should not only deal with the optimization of inulin extraction from different plants but also 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 from the nutritional, technological, and human health aspects.

Author Contributions: Conceptualization, G.N.Y., T.T. and I.Y.; writing—original draft preparation, G.N.Y.; writing—review and editing, G.N.Y., T.T. and M.S.O.; project administration, M.S.O.; funding acquisition, M.S.O. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by Cukurova University, Turkey, as part of the FDK-2021-14015 project.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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