Foods and Raw Materials. 2022;10(2)

ISSN 2310-9599 (Print)
ISSN 2308-4057 (Online)

Research Article
Open Access

Available online at http://jfrm.ru/en
https://doi.org/10.21603/2308-4057-2022-2-540
https://elibrary.ru/ZNGQOE

Carboxymethyl cellulose and psyllium husk in gluten-free pasta

Siham M.M. Faheid[1], Ibrahim R.S. Rizk[2], Yasser F.M. Kishk[2], Gamal H. Ragab[1], Sayed Mostafa[1,*]

[1] National Research Centre, Giza, Egypt
[2] Ain Shams University, Cairo, Egypt

* e-mail: abnody.sayed@gmail.com

Received 02.01.2022; Revised 18.03.2022; Accepted 05.04.2022; Published online 23.09.2022

Abstract:
Formulating high-quality pasta from wheat-free materials is a technological challenge. We aimed to make gluten-free pasta with carboxymethyl cellulose and psyllium husk and evaluate their effect on the quality of the final product.
Gluten-free pasta was produced from rice flour, white corn flour, potato starch, soy protein isolate, and carboxymethyl cellulose or psyllium husk used as binding agents. Then, we evaluated the effect of these hydrocolloids on the color, texture, cooking quality, and sensory characteristics of the product.
The uncooked gluten-free pasta containing psyllium husk showed significantly higher values of hardness compared to the samples with carboxymethyl cellulose, while the cooked pasta with psyllium husk had a significantly lower nitrogen loss. Also, psyllium husk improved the texture of the cooked gluten-free pasta, providing the highest values of resilience, springiness, and chewiness. Generally, the psyllium husk samples received higher quality values for texture, cooking quality, and sensory parameters, compared to the pasta with carboxymethyl cellulose.
Psyllium husk showed a better ability to bind gluten-free pasta than carboxymethyl cellulose. Consequently, psyllium husk could become a feasible alternative to wheat gluten in producing high-quality gluten-free pasta.

Keywords: Celiac, gluten free pasta, psyllium husk, carboxymethyl cellulose, potato starch, soy protein isolate

Please cite this article in press as: Faheid SMM, Rizk IRS, Kishk YFM, Ragab GH, Mostafa S. Carboxymethyl cellulose and psyllium husk in gluten-free pasta. Foods and Raw Materials. 2022;10(2):329–339. https://doi.org/10.21603/2308-4057-2022-2-540

INTRODUCTION

Functional foods that are consumed as part of a regular diet have the potential to improve health or reduce disease risk. For example, gluten-free foods are particularly useful for celiac patients [1]. Preventive medicine has made significant progress in the previous decade and proved the critical importance of nutrition in avoiding diseases, particularly those related to diet [2].

Celiac disease is a chronic inflammatory autoimmune disease of the small intestine mucosa triggered by the consumption of gluten proteins [3]. It is characterized by a lifelong intolerance to gluten, specifically the prolamin portion of wheat (gliadin), rye (secalin), and barley (hordein) [4].

Today, 1% of the world's population has celiac disease [5]. A life-long rigorous gluten-free diet is currently the only treatment available for celiac patients. It improves the quality of life, prevents refractory celiac disease, and alleviates symptoms [6]. In the long run, this diet also benefits patients with previously unexplained persistent watery diarrhea or dominating bloating symptoms who satisfy the criteria for functional bowel disorders [7]. Thus, gluten-free food production must be prioritized to meet the needs of people with celiac disease [8].

Gluten-free pasta is one of the options for people with celiac disease caused by their inability to digest gluten adequately [9]. Gluten-intolerant people, who are becoming more common in society, will prefer this product to gluten-containing pasta [10].

Pasta is generally regarded as a classic food product that is frequently consumed due to its sensory qualities, as well as convenience and ease of transportation, cooking, handling, and storage. In addition, pasta has grown popular due to its nutritional qualities that

Copyright © 2022, Faheid *et al.* This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), allowing third parties to copy and redistribute the material in any medium or format and to remix, transform, and build upon the material for any purpose, even commercially, provided the original work is properly cited and states its license.

are linked to a low glycemic index. In short-term human intervention studies, low-glycemic-index foods reduced appetite and increased fullness [11]. However, people with celiac disease prefer gluten-free pasta for health reasons [12].

Rice flour has been included in gluten-free product formulations to give the batter structure and nutritional value [13]. It is a primary ingredient in pasta production [14]. Furthermore, the use of rice flour is appealing because of its low salt content and high digestibility [15].

Hydrocolloids are commonly used as thickening agents that increase dough viscosity and bind water to improve texture, volume, and final quality. In addition to their advantages for the technological properties of gluten-free products, hydrocolloids may impact the final product's glycemic index [16]. Particularly, fiber increases satiety after eating and reduces the glycemic index of food [17]. As a result, hydrocolloids such as psyllium husk are particularly crucial materials for gluten-free flour [18].

In addition, using psyllium in cooking may help celiacs live longer by allowing them to eat fiber with regular meals rather than separately as a supplement, which may not be as tasty [19]. On the other hand, the consumption of soybean food or fortified foods has recently increased due to its benefits for human nutrition and health [20].

Gluten-free pasta is more expensive and it is often brittle and pale compared to wheat flour pasta [21]. Therefore, we aimed to produce high-quality gluten-free pasta from various formulas fortified with soy protein isolate and two types of hydrocolloids (psyllium husk or carboxymethyl cellulose), as well as to evaluate the physicochemical and sensory characteristics of the final product.

STUDY OBJECTS AND METHODS

Our study involved the production and evaluation of gluten-free pasta made from white corn flour, rice flour, soy protein isolate, psyllium husk, and carboxymethyl cellulose.

Materials. Wheat flour with 72% extraction (11.31% protein, 0.95% protein, 0.57% ash, 0.66% fiber, and 86.51% nitrogen-free extract) was obtained from Amoun Milling Company (Giza, Egypt). Rice flour (7.16% protein, 1.50% protein, 0.57% ash, 1.21% fiber, and 89.56% nitrogen-free extract) and white corn flour (9.76% protein, 4.24% protein, 1.27% ash, 2.94% fiber, and 81.79% nitrogen-free extract) were obtained from the local market (Giza, Egypt). Soy protein isolate (87.74% protein, 0.43% protein, 2.87% ash, 0.29% fiber, and 8.67% nitrogen-free extract) was obtained from American Food Chemicals. Potato starch (0.16% protein, 0.17% protein, 0.03% ash, 0.01% fiber, and 99.63% nitrogen-free extract) was obtained from Emsland Group, Germany. Carboxymethyl cellulose was obtained from Sigma Company. Psyllium husk powder (*Plantago psyllium* L.) was obtained from Now Foods, USA. All the chemicals used in the estimation and analysis were of analytical grade.

Methods.

Technological methods.

Preparation of composite flour. Wheat flour (72% ext.) pasta was used as a control sample. The experimental samples, in addition to gluten-free flours, contained soy protein isolate and psyllium husk or carboxymethyl cellulose, with varying levels of white corn flour, rice flour, and potato starch (Table 1). Individual flour combinations were homogenized, sealed in polyethylene bags, and stored at –18°C until needed.

Pasta dough preparation. Pasta was produced according to Collins and Pangloli with some modifications [22]. All dry ingredients were sieved through a 100-mesh sieve, combined, and mixed to produce a homogenized mixture. Then, the mixture was placed in a mixing bowl and mixed until the dough formed (31 ± 1% of tap water). The dough was shaped into a ball, covered with a plastic wrap, and allowed to rest for 30 min. Then, it was hand-kneaded for 1 min, divided into 100-g portions, and shaped in a cylindrical

Table 1 Pasta formulas

Samples	Raw materials, g						
	Wheat flour	White corn flour	Rice flour	Potato starch	Soy protein isolate	Psyllium husk	Carboxymethyl cellulose
Control	100.00	–	–	–	–	–	–
A	–	45.0	45.0	–	10	2.5	–
B	–	37.5	37.5	15.0	10	2.5	–
C	–	30.0	30.0	30.0	10	2.5	–
D	–	22.5	22.5	45.0	10	2.5	–
E	–	15.0	15.0	60.0	10	2.5	–
F	–	45.0	45.0	–	10	–	2.5
G	–	37.5	37.5	15.0	10	–	2.5
H	–	30.0	30.0	30.0	10	–	2.5
I	–	22.5	22.5	45.0	10	–	2.5
J	–	15.0	15.0	60.0	10	–	2.5

form by using a pasta machine without vacuum (Philips Pasta Maker HR 2357/05, Italy).

Pasta drying process. In line with Kishk *et al.*, the pasta samples were air-dried at 23–25°C for 4 h in a room equipped with a fan [23]. After drying in the open air, the samples were placed in a cabinet dehydrator and dried at 70°C to a moisture level of about 12%. After cooling to room temperature (25 ± 2°C), the samples were placed in plastic bags, sealed, and stored at 12–14°C until analysis.

Analytical methods.

Color determination. The color of the samples was measured according to Humter by using a Hunter Lab colorimeter [24]. L^*, a^*, and b^* parameters were measured by a spectro-colorimeter (Tristimulus Color Machine) with a CIELAB color scale (Hunter Lab Scan XE-Reston VA, USA) and the reflection mode. The instrument was standardized with white tiles (Hunter Lab Color Standard (LX No.16379), $X = 72.26$, $Y = 81.94$, and $Z = 88.14$ ($L^* = 92.46$, $a^* = –0.86$; $b^* = –0.16$)). The instrument (65°/0° geometry; D25 optical sensor; 10° observer) was calibrated by using black and white reference tiles. The color values were expressed as lightness to darkness for L^*, redness to greenness for a^*, and yellowness to blueness for b^*.

Physical properties of pasta. Pasta cooking quality was determined according to the method approved by the American Association of Cereal Chemists [25]. Optimum cooking time was the time required for the opaque core of the pasta to disappear when squeezed gently between two glass plates after cooking. Pasta pieces of 25 g were cooked for optimum time in a beaker with 300 mL of tap water, rinsed in cold water, drained for 15 min, and weighed. The percentage of increased weight was calculated as a cooking yield.

The content of solids in the cooking water was determined by drying at 105°C overnight. The cooking loss was expressed as a percentage between the solid weight and the initial dry matter. To calculate the swelling index, we divided the difference between the weight of cooked and uncooked pasta by the weight of uncooked pasta. The nitrogen loss was determined according to the Kjeldahl method approved by the American Association of Cereal Chemists by using conversion factor of 5.7 [25].

Texture profile analysis of pasta. The texture of the pasta samples (hardness, springiness, cohesiveness, chewiness, gumminess, and resilience) was determined by Texture Profiles Analysis (TPA) using a CT3™ Texture Analyzer (Brookfield) according to Boume [26]. The Test Works software was installed and an appropriate test was selected for the TPA analysis: a 2.50 mm/s test speed, a 10 000 g load cell, two cycles for cooked pasta, one cycle for uncooked pasta, and a 10 mm depth. The parameters, such as length, diameter, speed, compression percentage, and the number of cycles, were entered as input data before starting the compression. Then the load cell started to slowly move downwards, compressing the sample, with a 5-s wait between the first and the second compression cycles. After two cycles, the compression stopped automatically.

Sensory evaluation of pasta. The sensory attributes of the gluten-free pasta were evaluated by ten panelists from the Department of Food Technology, National Research Centre, according to the method reported by Inglett *et al.* [27]. Color, texture, flavor, and overall acceptability were evaluated on the 9-point hedonic scale. The scale was verbally anchored with nine categories, namely: like extremely, like very much, like moderately, like slightly, neither like nor dislike, dislike slightly, dislike moderately, dislike very much, and dislike extremely. The quality attributes of the experimental samples were compared with those of the control sample (100% wheat flour).

Statistical analysis. The results were analyzed statistically by performing analysis of variance (ANOVA) and Duncan's multiple range test in the SPSS statistical package (Version 9.05). The least significant difference was chosen to determine significant differences among various formulations. Differences were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

We studied effects of psyllium husk (2.5%) and carboxymethyl cellulose (2.5%) on gluten-free pasta with different proportions of white corn flour, rice flour, potato starch, and a fixed amount of soy protein isolate (10%).

Color parameters of gluten-free uncooked pasta. The color parameters (L^*, a^*, b^*, and color intensity) of the uncooked pasta samples are presented in Table 2. As we can see, the samples containing potato starch (60%) and carboxymethyl cellulose or psyllium husk (samples J and E, respectively) recorded the highest values of L^* color (more lightness) with significant differences between them or in comparison with the other samples ($P \leq 0.05$).

We also found that lightness was affected by the amount of potato starch in the samples: the more potato starch, the lighter the samples. The control sample had the lowest value of lightness. The highest values of redness (a^* value) were observed in the control sample (3.22) and the sample with carboxymethyl cellulose and without potato starch (2.52). However, there were no significant differences in redness among the rest of the samples.

As for yellowness (b^* values), the lowest value (13.20) was recorded in the control sample, while the highest values (16.70 and 15.93) were observed in the samples without potato statrch (samples A and F). There were no significant differences in yellowness among the gluten-free samples with soy protein isolate. However, the highest value of color intensity was found in the sample containing 60% potato starch + carboxymethyl cellulose, in contrast to the control sample with the lowest value. These results were consistent with those of Bolarinwa and Oyesiji who reported that gluten-free

Table 2 Color parameters of uncooked wheat flour pasta and gluten-free pasta with psyllium husk or carboxymethyl cellulose

Samples	Color parameters			
	*L** (lightens)	*a** (redness)	*b** (yellowness)	Color intensity
Control	61.73[i]	3.22[a]	13.20[d]	1.510[d]
Gluten-free pasta with psyllium husk:				
A (0% of potato starch)	68.86[h]	1.77[c]	15.93[ab]	1.530[c]
B (15%)	70.36[g]	1.67[cd]	15.30[bc]	1.530[c]
C (30%)	71.90[f]	1.57[cd]	14.73[bc]	1.540[b]
D (45%)	73.96[d]	1.49[cd]	14.33[c]	1.540[b]
E (60%)	75.70[b]	1.46[cd]	14.26[c]	1.540[b]
Gluten-free pasta with carboxymethyl cellulose:				
F (0% of potato starch)	69.50[h]	2.52[b]	16.70[a]	1.530[c]
G (15%)	70.86[g]	1.71[cd]	15.60[ab]	1.536[b]
H (30%)	72.80[e]	1.68[cd]	15.23[bc]	1.540[b]
I (45%)	74.86[c]	1.36[cd]	15.16[bc]	1.540[b]
J (60%)	77.50[a]	1.29[d]	15.06[bc]	1.550[a]

Means in the same column with different letters are significantly different ($P \leq 0.05$)

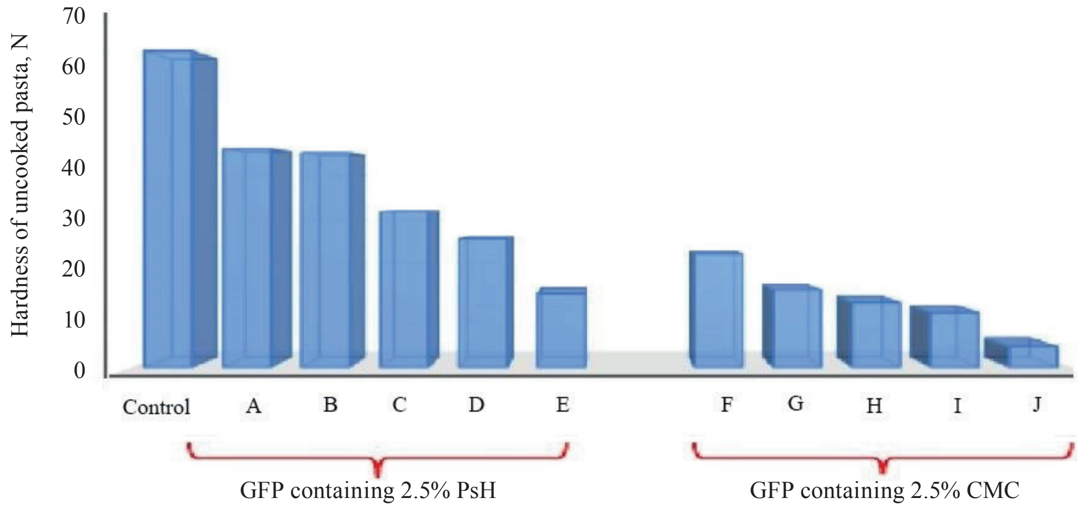

Figure 1 Texture profile analysis of uncooked pasta: Control – 100 % wheat flour pasta; A, F – no potato starch; B, G – 15% of potato starch; C, H – 30% of potato starch; D, I – 45% of potato starch; E, J – 60% of potato starch

pasta with rice and corn flour had higher lightness and lower redness compared to wheat flour pasta [28].

The hardness of gluten-free uncooked pasta. Hardness (N) is related to the strength of structure under compression during the first compression cycle. It is a force required to attain a given deformation. The hardness of uncooked pasta was determined by the texture profile analyzer (Fig. 1).

As can be seen, the control pasta showed the highest value of hardness (65.13) compared to the gluten-free samples, which reflected the strength of structure provided by the gluten network.

However, there was a clear difference in hardness between the samples with psyllium husk and those with carboxymethyl cellulose. Particularly, the highest hardness (44.97) was recorded in the psyllium husk sample without potato starch (sample A) compared to the carboxymethyl cellulose samples without starch (sample F) (23.30).

In general, the psyllium husk pasta had hardness values in the range of 44.97 to 15.16, whereas the carboxymethyl cellulose samples had this parameter ranging from 23.30 to 4.26. Thus, potato starch played an important role in the hardness of uncooked pasta: higher contents of potato starch led to lower hardness. These results were confirmed by Kang *et al.* who found that the hardness of gluten-free pasta containing potato starch was lower than that of wheat flour pasta [29].

Color parameters of gluten-free cooked pasta. The color parameters of the cooked pasta samples are presented in Table 3 and Fig. 2. As we can see, the samples containing 60% potato starch and

Table 3 Color parameters of cooked wheat flour pasta and gluten-free pasta with psyllium husk or carboxymethyl cellulose

Samples	Color parameters			
	L^* (lightens)	a^* (redness)	b^* (yellowness)	Color intensity
Control	52.70[c]	2.80[ab]	19.20[b]	1.50[b]
Gluten-free pasta with psyllium husk:				
A (0% of potato starch)	57.84[b]	3.03[a]	21.23[a]	1.51[a]
B (15%)	57.94[b]	2.90[ab]	20.40[ab]	1.51[a]
C (30%)	58.57[b]	2.83[ab]	20.20[ab]	1.51[a]
D (45%)	58.80[b]	2.73[b]	19.46[b]	1.51[a]
E (60%)	60.70[a]	2.33[c]	16.40[c]	1.51[a]
Gluten-free pasta with carboxymethyl cellulose:				
F (0% of potato starch)	57.90[b]	3.03[a]	21.23[a]	1.51[a]
G (15%)	58.50[b]	2.90[ab]	20.33[ab]	1.51[a]
H (30%)	58.80[b]	2.76[b]	19.53[b]	1.51[a]
I (45%)	58.90[b]	2.73[b]	19.40[b]	1.51[a]
J (60%)	61.66[a]	2.10[d]	14.76[d]	1.51[a]

Means in the same column with different letters are significantly different ($P \leq 0.05$)

carboxymethyl cellulose or psyllium husk (samples J and E) recorded the highest values of L^* (more lightness), with no significant difference between them. However, they showed significant differences when compared to the other samples ($P \leq 0.05$). Consequently, lightness was affected by the content of potato starch in the samples, with higher contents leading to lighter color. The control sample had the lowest value of lightness.

The highest redness (a^*) values were recorded in the samples containing 45% white corn flour, 45% rice flour, 10% soy protein isolate, and 2.5% carboxymethyl cellulose or 2.5% psyllium husk, with no significant differences. The lowest redness was observed in the samples containing 60% potato starch with 2.5% carboxymethyl cellulose or 2.5% psyllium husk. However, the lowest value of color intensity was significantly recorded in the control sample, with no significant differences between the gluten-free samples.

Our results were in agreement with those of Yaseen and Shouk [30]. The authors found that pasta with corn starch had higher lightness and lower redness values compared to the control (100% wheat flour). Similarly, Mohammadi *et al.* reported that increased amounts of rice flour in gluten-free products led to higher lightness of the final product [31].

The quality of gluten-free cooked pasta. The cooking time and quality parameters of the pasta samples prepared with hydrocolloids (carboxymethyl cellulose and psyllium husk) are presented in Table 4. As can be seen, the optimum cooking time was highest (13.16 min) for the control sample ($P \leq 0.05$) compared to the other samples except for the samples without potato starch (A and F). However, the optimum cooking time gradually decreased with higher contents of potato starch. Also, potato starch had a positive effect on the cooking yield, whether the samples contained carboxymethyl cellulose or psyllium husk as binding agents.

The swelling index of pasta is an indicator of how much water is absorbed by starch and proteins during cooking. It is utilized for the gelatinization of starch and hydration of proteins [32]. According to Table 4, the swelling index was the lowest (142.82) for the control sample and highest (190.60) for the psyllium husk sample with 60% of potato starch (sample E), with significant difference. The swelling index was also high (186.66) for the carboxymethyl cellulose with 60% of starch (sample J).

Cooking loss is defined as the quantity of solids going into water during cooking. It determines the quality of pasta, with compact-textured pasta having a lower cooking loss [33]. According to our results (Table 4), the control sample significantly recorded the lowest value of cooking loss (6.16%). We also found that potato starch had a negative effect on the quality of the gluten-free pasta, i.e., higher contents of potato starch gradually increased cooking loss. However, this negative effect was reduced by adding psyllium husk.

The results also showed a significantly high value of nitrogen loss in the gluten-free samples with carboxymethyl cellulose, compared to the control and the samples with psyllium husk. Moreover, potato starch significantly increased nitrogen loss in the carboxymethyl cellulose samples. In general, nitrogen loss ranged from 12.10 to 40.55% in the samples with carboxymethyl cellulose and from 6.50 to 10.20% in the samples with psyllium husk.

In the study by De Arcangelis *et al.*, such hydro-thermal treatments inhibited granule swelling, retarded gelatinization, and increased starch paste stability, having thus enhanced the texture properties and cooking

Table 4 Cooking time and quality parameters of cooked wheat flour pasta and gluten-free pasta with psyllium husk or carboxymethyl cellulose

Samples	Optimum cooking time	Cooking yield	Swelling index	Cooking loss	Nitrogen loss
Control	13.16^{a}	136.93^{g}	142.83^{h}	6.16^{j}	4.00^{h}
Gluten-free pasta with psyllium husk:					
A (0% of potato starch)	12.83^{ab}	144.80^{f}	159.43^{f}	6.83^{i}	6.50^{gh}
B (15%)	12.50^{b}	152.60^{e}	171.46^{e}	7.36^{h}	6.80^{g}
C (30%)	12.00^{c}	160.40^{d}	178.43^{d}	8.30^{g}	7.30^{g}
D (45%)	11.33^{d}	175.40^{b}	182.80^{c}	8.90^{f}	9.00^{fg}
E (60%)	10.16^{e}	183.80^{a}	190.60^{a}	9.80^{e}	10.20^{ef}
Gluten-free pasta with carboxymethyl cellulose:					
F (0% of potato starch)	13.00^{a}	120.80^{h}	150.00^{g}	9.70^{e}	12.10^{e}
G (15%)	12.00^{c}	132.80^{g}	157.53^{f}	11.43^{d}	17.30d
H (30%)	11.33^{d}	142.40^{f}	169.33^{e}	13.30^{c}	21.60^{c}
I (45%)	10.33^{e}	154.40^{e}	182.93^{c}	15.40^{b}	34.50^{b}
J (60%)	10.00^{e}	166.40^{c}	186.66^{bc}	18.76^{a}	40.55^{a}

Means in the same column with different letters are significantly different ($P \leq 0.05$)

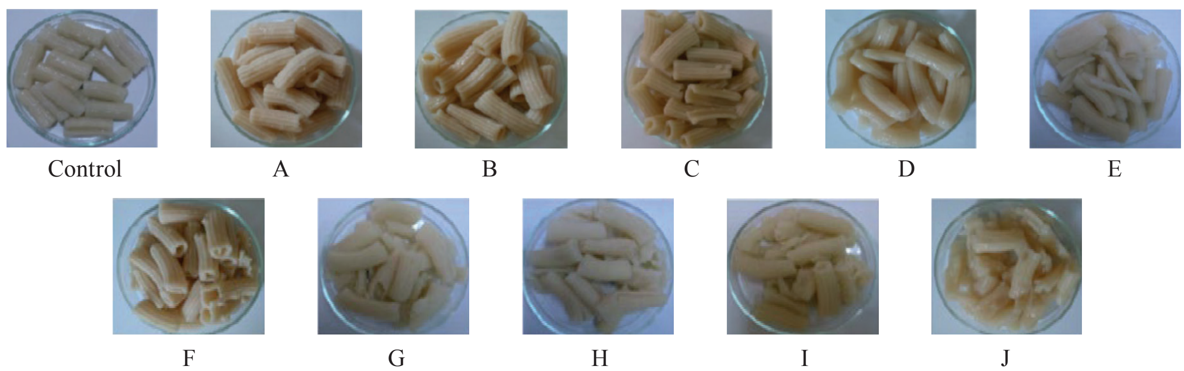

Figure 2 Gluten-free pasta samples: Control – 100% wheat flour; A – psyllium husk without potato starch ; B – psyllium husk + 15% of potato starch; C – psyllium husk + 30% of potato starch; D – psyllium husk + 45% of potato starch; E – psyllium husk + 60% of potato starch; F – carboxymethyl cellulose without potato starch; G – carboxymethyl cellulose + 15% of potato starch; H – carboxymethyl cellulose + 30% of potato starch; I – carboxymethyl cellulose + 45% of potato starch; J – carboxymethyl cellulose + 60% of potato starch

behavior of rice noodles [32]. Further, Khosla *et al.* reported that higher contents of rice flour in gluten-free pasta might increase the optimum cooking time [34].

The texture profile of gluten-free cooked pasta. The textural properties of cooked pasta are an important parameter that determines the overall acceptability by consumers [35]. The results of texture profile analysis of our gluten-free cooked pasta against the control (100% wheat flour) are shown in Table 5.

During the first bite, we obtained hardness, adhesiveness, and resilience values.

Hardness is defined as the maximum load applied to the samples during a compression cycle, corresponding to the peak force [36]. According to Table 5, the control pasta recorded the highest value of cycle 1 hardness (3.96 N) compared to the gluten-free samples. This result was in agreement with Larrosa *et al.* who stated that wheat control pasta showed higher hardness values than all gluten-free tagliatelles, demonstrating the impact of the gluten matrix on tagliatelle texture [37].

In our study, the gluten-free samples with psyllium husk had higher hardness values than those with carboxymethyl cellulose, ranging from 3.31 to 1.76 N and from 1.73 to 0.69 N, respectively. We also found that higher contents of potato starch decreased the hardness values in all gluten-free samples. Similarly, Detchewa *et al.* reported an increase in the hardness of gluten-free spaghetti when hydrocolloids were incorporated [38].

Adhesiveness measures the extent to which the product gets attached to teeth and is considered the most undesirable characteristic of pasta [39]. According to Table 5, the control pasta recorded the lowest value of adhesiveness (0.1 mJ). As for the gluten-free pasta, the samples with psyllium husk had lower

Table 5 Texture profile analysis of cooked pasta under study

Samples	First bite			Second bite				
	Hardness cycle 1, N	Adhesiveness, mJ	Resilience	Hardness cycle 2, N	Cohesiveness	Springiness, mm	Gumminess	Chewiness, mJ
Control	3.96	0.1	0.61	3.74	0.90	4.95	3.56	17.64
Gluten-free pasta with psyllium husk:								
A (0% of potato starch)	3.31	0.2	0.57	3.16	0.75	4.58	2.48	11.37
B (15%)	3.11	0.2	0.53	2.94	0.66	4.33	2.05	8.89
C (30%)	2.33	0.2	0.45	1.93	0.45	4.24	1.05	4.45
D (45%)	1.84	0.3	0.36	1.26	0.42	3.67	0.77	2.84
E (60%)	1.76	0.3	0.32	0.84	0.38	3.34	0.67	2.23
Gluten-free pasta with carboxymethyl cellulose:								
F (0% of potato starch)	1.73	0.3	0.55	1.64	0.83	4.30	1.09	4.69
G (15%)	1.46	0.4	0.36	0.87	0.43	4.04	0.63	2.54
H (30%)	1.44	0.5	0.14	0.72	0.32	3.79	0.46	1.75
I (45%)	1.22	0.6	0.12	0.64	0.05	2.19	0.06	0.13
J (60%)	0.69	0.7	0.10	0.56	0.04	1.80	0.03	0.05

values of adhesiveness (0.2–0.3 mJ) than those with carboxymethyl cellulose (0.3–0.7 mJ).

These results reflect the good quality of the control wheat pasta compared to the gluten-free pasta. They also show that psyllium husk improved the quality of gluten-free pasta compared to the samples with carboxymethyl cellulose. Piwinska *et al.* reported such special qualities of durum wheat pasta as high hardness, low adhesiveness, low cooking loss, and tolerance to overcooking [40].

During the second bite, we obtained hardness, cohesiveness, springiness, gumminess, and chewiness values (Table 5). As we can see, the control had a lower value of hardness (3.74 N) compared to the same sample in cycle 1 (3.96 N), with a decreasing rate of 5.55%. In the gluten-free pasta, the decreasing rate of hardness from cycle 1 to cycle 2 ranged from 4.53 to 52.27% in the samples with psyllium husk and from 5.20 to 47.54% in those with carboxymethyl cellulose. The maximum decrease was recorded in the carboxymethyl cellulose sample with 45% potato starch.

Cohesiveness quantifies the internal resistance of food structure and can be briefly defined as an ability of a material to stick to itself [41]. According to our results, the highest value of cohesiveness (0.90) was recorded in the control sample. Also, quite high (0.75) cohesiveness was in the psyllium husk sample without potato starch (sample A). We also found that cohesiveness values gradually decreased with the increasing contents of potato starch.

Springiness measures elasticity by determining the extent of recovery between the first and the second compression. According to our results, the control sample recorded the highest value of springiness (4.95 mm). In the gluten-free samples with psyllium husk, springiness ranged from 4.58 to 3.34 mm, whilst in those with carboxymethyl cellulose, from 4.30 to 1.80 mm. Also, the control sample recorded the highest values of gumminess and chewiness.

Among the gluten-free samples, those with psyllium husk had higher values of gumminess and chewiness than those with carboxymethyl cellulose. We found that higher contents of potato starch in the gluten-free samples decreased their gumminess and chewiness. These results showed a more positive effect of psyllium husk than carboxymethyl cellulose.

As reported by Udachan and Sahoo, the primary parameters of pasta quality are hardness, springiness, and cohesiveness (they should be higher), whereas the secondary parameters are chewiness and resilience [9]. Generally, our results were in agreement with Anisa *et al.* who stated that gluten-free pasta was characterized by lower hardness, gumminess, chewiness, and springiness, and it had higher adhesiveness than wheat pasta [42].

Sensory evaluation of gluten-free cooked pasta. Sensory evaluation is a unique tool that uses human senses to determine organoleptic characteristics of a food product and the consumer's attitude to it. Therefore, it is a reliable comprehensive test of the final product's quality. Additionally, sensory evaluation provides important reference information to be compared with the results of instrumental or chemical methods [43].

In our study, the cooked gluten-free pasta samples were evaluated on a hedonic scale, with a wheat sample (72% ext.) used as a control (Table 6). We found no significant differences ($P \leq 0.05$) in color between the control sample and those containing 15, 30, 45, and 60% of potato starch and 2.5% psyllium husk or 30, 45, and 60% of carboxymethyl cellulose. There were no significant differences in texture between the control sample and sample B containing 15% potato starch and 2.5% psyllium husk. Sample B had the most optimal

Table 6 Sensory characteristics of cooked wheat flour and gluten-free pasta

Samples	Color	Texture	Flavor	Taste	Appearance	OAA
Control	5.0[a]	5.0[a]	5.0[a]	5.0[a]	5.0[a]	5.0[a]
Gluten-free pasta with psyllium husk:						
A (0% of potato starch)	4.1[bc]	3.4[bc]	4.9[ab]	3.0[d]	3.8[c]	4.0[b]
B (15%)	4.5[ab]	4.6[a]	4.9[ab]	4.0[b]	4.5[b]	4.8[a]
C (30%)	5.1[a]	3.9[b]	4.8[ab]	3.8[bc]	4.0[c]	3.7[bc]
D (45%)	5.0[a]	3.3[cd]	4.7[ab]	3.3[cd]	3.3[d]	3.2[c]
E (60%)	5.0[a]	3.0[d]	4.7[ab]	2.4[e]	2.6[ef]	1.9[e]
Gluten-free pasta with carboxymethyl cellulose:						
F (0% of potato starch)	3.7[c]	3.7[bc]	4.8[ab]	3.3[cd]	3.3[d]	3.5[bc]
G (15%)	4.3[bc]	3.9[b]	4.7[ab]	3.7[bc]	3.9[c]	3.6[bc]
H (30%)	5.0[a]	3.0[d]	4.7[ab]	2.9[de]	2.7[e]	2.4[d]
I (45%)	5.0[a]	2.4[e]	4.5[b]	2.4[e]	2.2[f]	1.3[f]
J (60%)	5.0[a]	1.4[f]	4.0[c]	1.3[f]	1.2[g]	1.0[f]

Means in the same column with different letters are significantly different ($P \leq 0.05$)

content of potato starch among those containing psyllium husk as a binding agent, since increased levels of potato starch (30, 45, and 60%) significantly lowered the scores for texture. Also, psyllium husk had a more positive effect on texture than carboxymethyl cellulose, with the texture scores of 3.00–4.60 and 1.40–3.70, respectively.

As for flavor, there were no significant differences between the control and the gluten-free samples except for two carboxymethyl cellulose samples with 45 and 60% potato starch, respectively. Taste received the highest score (5.0) for the control sample ($P \leq 0.05$) followed by sample B (4.0) containing 15% potato starch and psyllium husk. While the best score for taste among the carboxymethyl cellulose samples was 3.7 for the sample with 15% potato starch, it was significantly different from the control sample but not from sample B.

The best scores for appearance were obtained by the control sample and the gluten-free sample containing psyllium husk and 15% of potato starch and (sample B), with significant differences. However, there were no significant differences between the sample containing psyllium husk and 30% of potato starch (sample C), and the one with carboxymethyl cellulose and 15% of potato starch and (sample G).

Overall acceptability showed no significant differences between the control and the gluten-free sample containing 15% potato starch and psyllium husk. In general, 15% was the most optimal content of potato starch in the samples with both psyllium and carboxymethyl cellulose. On the other hand, the samples with psyllium husk had a better effect on overall acceptability than those with carboxymethyl cellulose, with the scores of 1.90–4.80 and 1.0–3.50, respectively. Our results were consistent with a study by Bolarinwa and Oyesiji, where the acceptability of gluten-free rice-soy pasta was highly ranked for sensory attributes [28]. Additionally, Ribeiro *et al.* stated that incorporating legume flour in rice pasta resulted in acceptable scores for color, taste, flavor, and appearance [44]. Also, Peressini *et al.* reported that psyllium husk had a positive effect on sensory evaluation, improving overall acceptability [45].

CONCLUSION

Based on the overall results, we can conclude that hydrocolloids have an important effect on the physical and sensory characteristics of gluten-free pasta. The experimental samples with psyllium husk used as a binding agent had better texture properties due to an increased hardness of uncooked pasta, compared to the samples with carboxymethyl cellulose. Therefore, the cooked samples with psyllium husk showed better quality parameters such as swelling index, cooking loss, cooking yield, and nitrogen loss, compared to those with carboxymethyl cellulose.

CONTRIBUTION

S.M.M. Faheid was involved in the conceptualization, methodology, investigation, and visualization. I.R.S. Rizk was responsible for visualization, drafting of the manuscript, and supervision. G.H. Ragab took part in the investigation and drafting of the manuscript. Y.F.M. Kishk contributed to the conceptualization and data analysis. S.M. Mostafa was involved in the conceptualization, methodology, and writing the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

The authors are grateful to the Food Technology Department, Food Industries and Nutrition Institute, National Research Centre, Egypt for their assistance with the research and for providing the equipment required for measurements.

REFERENCES

1. Butnariu M, Sarac I. Functional food. International Journal of Nutrition. 2019;3(3):7–16. https://doi.org/10.14302/issn.2379-7835.ijn-19-2615
2. Moghadam FH, Khalghani J, Moharramipour S, Gharali B, Mohasses MM. Investigation of the induced antibiosis resistance by zinc element in different cultivars of sugar beet to long snout weevil, *Lixus incanescens* (Col: Curculionidae). Banat's Journal of Biotechnology. 2018;9(17):5–12 https://doi.org/10.7904/2068-4738-IX(17)-5
3. Lebwohl B, Sanders DS, Green, PHR. Coeliac disease. The Lancet. 2018;391(10115):70–81. https://doi.org/10.1016/S0140-6736(17)31796-8
4. Lexhaller B, Colgrave ML, Scherf KA. Characterization and relative quantitation of wheat, rye, and barley gluten protein types by liquid chromatography–tandem mass spectrometry. Frontiers in Plant Science. 2019;10. https://doi.org/10.3389/fpls.2019.01530
5. Weisbrod VM, Silvester JA, Raber C, McMahon J, Coburn SS, Kerzner B. Preparation of gluten-free foods alongside gluten-containing food may not always be as risky for celiac patients as diet guides suggest. Gastroenterology. 2020;158(1):273–275. https://doi.org/10.1053/j.gastro.2019.09.007
6. Caio G, Volta U, Sapone A, Leffler DA, De Giorgio R, Catassi, C, *et al.* Celiac disease: a comprehensive current review. BMC Medicine. 2019;17(1). https://doi.org/10.1186/s12916-019-1380-z
7. Fernández-Bañares F, Arau B, Raga A, Aceituno M, Tristán E, Carrasco A, *et al.* Long-term effect of a gluten-free diet on diarrhea or bloating-predominant functional bowel disease: Role of the "low-grade coeliac score" and the "coeliac lymphogram" in the response rate to the diet. Nutrients. 2021;13(6). https://doi.org/10.3390/nu13061812
8. Remes-Troche JM, Uscanga-Domínguez LF, Aceves-Tavares RG, Calderón de la Barca AM, Carmona-Sánchez RI, Cerda-Contreras E, *et al.* Clinical guidelines on the diagnosis and treatment of celiac disease in Mexico. Revista de Gastroenterología de México. 2018;83(4):434–450. https://doi.org/10.1016/j.rgmx.2018.05.005
9. Udachan IS, Sahoo AK. Effect of hydrocolloids in the development of gluten free brown rice pasta. International Journal of ChemTech Research. 2017;10(6):407–415.
10. Sissons M. Development of novel pasta products with evidence based impacts on health – A review. Foods. 2022;11(1). https://doi.org/10.3390/foods11010123
11. Atkinson FS, Brand-Miller JC, Foster-Powell K, Buyken AE, Goletzke J. International tables of glycemic index and glycemic load values 2021: a systematic review. The American Journal of Clinical Nutrition. 2021;114(5):1625–1632. https://doi.org/10.1093/ajcn/nqab233
12. Levinta A, Mukovozov I, Tsoutsoulas C. Use of a gluten-free diet in schizophrenia: A systematic review. Advances in Nutrition. 2018;9(6):824–832. https://doi.org/10.1093/advances/nmy056
13. Bouasla A, Wojtowicz A, Zidoune MN. Gluten-free precooked rice pasta enriched with legumes flours: Physical properties, texture, sensory attributes and microstructure. LWT – Food Science and Technology. 2017;75:569–577. https://doi.org/10.1016/j.lwt.2016.10.005
14. Bouasla A, Wojtowicz A. Rice-buckwheat gluten-free pasta: Effect of processing parameters on quality characteristics and optimization of extrusion-cooking process. Foods. 2019;8(10). https://doi.org/10.3390/foods8100496
15. Phongthai S, D'Amico S, Schoenlechner R, Homthawornchoo W, Rawdkuen S. Fractionation and antioxidant properties of rice bran protein hydrolysates stimulated by *in vitro* gastrointestinal digestion. Food Chemistry. 2018;240:156–164. https://doi.org/10.1016/j.foodchem.2017.07.080
16. Culetu A, Duta DE, Papageorgiou M, Varzakas T. The role of hydrocolloids in gluten-free bread and pasta; Rheology, characteristics, staling and glycemic index. Foods. 2021;10(12). https://doi.org/10.3390/foods10123121
17. Zhu R, Larsen TM, Fogelholm M, Poppitt SD, Vestentoft PS, Silvestre MP, *et al.* Dose-dependent associations of dietary glycemic index, glycemic load, and fiber with 3-year weight loss maintenance and glycemic status in a high-risk population: a secondary analysis of the diabetes prevention study. PREVIEW. Diabetes Care. 2021;44(7):1672–1681. https://doi.org/10.2337/dc20-3092
18. Herawati H. Hydrocolloids to the effects of gluten free bakery products. Journal of Physics: Conference Series. 2019;1295(1). https://doi.org/10.1088/1742-6596/1295/1/012052
19. Fradinho P, Soares R, Niccolai A, Sousa I, Raymundo A. *Psyllium* husk gel to reinforce structure of gluten-free pasta? LWT. 2020;131. https://doi.org/10.1016/j.lwt.2020.109787

20. Mishra P, Bhatt DK. Development of quality characteristics of dried pasta enriched with soya protein isolate powder. IOSR Journal of Environmental Science, Toxicology and Food Technology. 2017;11(10):1–6.

21. Scarton M, Ribeiro T, Godoy HT, Behrens JH, Campelo PH, Clerici MTPS. Gluten free pasta with natural ingredient of color and carotene source. Research, Society and Development. 2021;10(4). https://doi.org/10.33448/rsd-v10i4.13959

22. Collins JL, Pangloli P. Chemical, physical and sensory attributes of noodles with added sweetpotato and soy flour. Journal of Food Science. 19976;62(3):622–625. https://doi.org/10.1111/j.1365-2621.1997.tb04446.x

23. Kishk YF, Elsheshetawy HE, Mahmoud EAM. Influence of isolated flaxseed mucilage as a non-starch polysaccharide on noodle quality. International Journal of Food Science and Technology. 2011;46(3):661–668. https://doi.org/10.1111/j.1365-2621.2010.02547.x

24. Hunter RS. Photoelectric color difference meter. Journal of the Optical Society of America. 1958;48(12):985–995. https://doi.org/10.1364/JOSA.48.000985

25. Approved method of the American Association of Cereal Chemists. 10th ed. Minnesota: AACC; 2000.

26. Boume M. Food texture and viscosity. Concept and measurement. 2nd. ed. London: Academic press; 2002. pp.257–290.

27. Inglett GE, Peterson SC, Carriere CJ, Maneepun S. Rheological, textural, and sensory properties of Asian noodles containing an oat cereal hydrocolloid. Food Chemistry. 2005;90(1–2):1–8. https://doi.org/10.1016/j.foodchem.2003.08.023

28. Bolarinwa IF, Oyesiji OO. Gluten free rice-soy pasta: proximate composition properties and sensory attributes. Heliyon. 2021;7(1). https://doi.org/10.1016/j.heliyon.2021.e06052

29. Kang J, Lee J, Choi M, Jin Y, Chang D, Chang YH, *et al.* Physicochemical and textural properties of noodles prepared from different potato varieties. Preventive Nutrition and Food Science. 2017;22(3):246–250. https://doi.org/10.3746/pnf.2017.22.3.246

30. Yaseen A, Shouk AE. Low phenylalanine pasta. International Journal of Nutrition and Metabolism. 2011;3(10): 128–135.

31. Mohammadi M, Khorshidian N, Yousefi M, Khaneghah AM. Physicochemical, rheological, and sensory properties of gluten-free cookie produced by flour of chestnut, date seed, and modified starch. Journal of Food Quality. 2022;2022. https://doi.org/10.1155/2022/5159084

32. De Arcangelis E, Cuomo F, Trivisonno MC, Marconi E, Messia MC. Gelatinization and pasta making conditions for buckwheat gluten-free pasta. Journal of Cereal Science. 2020;95. https://doi.org/10.1016/j.jcs.2020.103073

33. Espinosa-Solis V, Zamudio-Flores PB, Tirado-Gallegos JM, Ramírez-Mancinas S, Olivas-Orozco GI, Espino-Díaz M, *et al.* Evaluation of cooking quality, nutritional and texture characteristics of pasta added with oat bran and apple flour. Foods. 2019;8(8). https://doi.org/10.3390/foods8080299

34. Khosla R, Rathi N, Gururani P, Upadhyay S, Singh M. Development and physichochemical analysis of gluten free pasta using rice, corn and flaxseeds. International Journal of Recent Scientific Research. 2019;10(05):32300–32305.

35. Ainsa A, Roldan S, Marquina PL, Roncalés P, Beltrán JA, Calanche Morales JB. Quality parameters and technological properties of pasta enriched with a fish by-product: A healthy novel food. Journal of Food Processing and Preservation. 2022;46(2). https://doi.org/10.1111/jfpp.16261

36. Peleg M. The instrumental texture profile analysis revisited. Journal of Texture Studies. 2019;50(5):362–368. https://doi.org/10.1111/jtxs.12392

37. Larrosa V, Lorenzo G, Zaritzky N, Califano, A. Improvement of the texture and quality of cooked gluten-free pasta. LWT. 2016;70:96–103. https://doi.org/10.1016/j.lwt.2016.02.039

38. Detchewa P, Prasajak P, Phungamngoen C, Sriwichai W, Naivikul O, Moongngarm A. Substitution of rice flour with rice protein improved quality of gluten-free rice spaghetti processed using single screw extrusion. LWT. 2021;153. https://doi.org/10.1016/j.lwt.2021.112512

39. Chauhan A, Saxena DC, Singh S. Effect of hydrocolloids on microstructure, texture and quality characteristics of gluten-free pasta. Journal of Food Measurement and Characterization. 2017;11(3):1188–1195. https://doi.org/10.1007/s11694-017-9495-4

40. Piwinska M, Wyrwisz J, Kurek MA, Wierzbicka A. Effect of drying methods on the physical properties of durum wheat pasta. CYTA – Journal of Food 2016;14(4):523–528. https://doi.org/10.1080/19476337.2016.1149226
41. Hosseini Ghaboos SH, Seyedain Ardabili SM, Kashaninejad M. Physico-chemical, textural and sensory evaluation of sponge cake supplemented with pumpkin flour. International Food Research Journal. 2018;25(2):854–860.
42. Ainsa A, Vega A, Honrado A, Marquina P, Roncales P, Gracia JAB, *et al.* Gluten-free pasta enriched with fish by-product for special dietary uses: Technological quality and sensory properties. Foods. 2021;10(12). https://doi.org/10.3390/foods10123049
43. Tóth M, Kaszab T, Meretei A. Texture profile analysis and sensory evaluation of commercially available glutenfree bread samples. European Food Research and Technology. 2022;248(6):1447–1455. https://doi.org/10.1007/s00217-021-03944-2
44. Ribeiro THS, Bolanho BC, Montanuci FD, Ruiz SP. Physicochemical and sensory characterization of gluten-free fresh pasta with addition of passion fruit peel flour. Ciência Rural. 2018;48(12). https://doi.org/10.1590/0103-8478cr20180508
45. Peressini D, Cavarape A, Brennan MA, Gao J, Brennan CS. Viscoelastic properties of durum wheat doughs enriched with soluble dietary fibres in relation to pasta-making performance and glycaemic response of spaghetti. Food Hydrocolloids. 2020;102. https://doi.org/10.1016/j.foodhyd.2019.105613

ORCID IDs
Siham M.M. Faheid https://orcid.org/0000-0002-1692-4174
Yasser F.M. Kishk https://orcid.org/0000-0003-3745-2775
Gamal H. Ragab https://orcid.org/0000-0002-5180-168X
Sayed M. Mostafa https://orcid.org/0000-0002-3770-8024