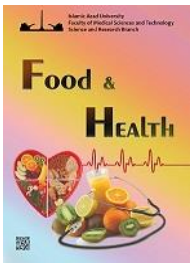

Food & Health Journal

Journal homepage: fh.srbiau.ac.ir

Study of the Effect of Quinoa Flour and Gellan Gum Replacement on the Physicochemical and Organoleptic Properties of Low-Fat Hamburgers

Maryam Shariat [1], Hamed Ahari [*1], Shadi Mahdikhani [2], Sima Moradi [3], Seyed Amir Ali Anvar [3]

[1] Department of Food Science and Technology, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[2] Department of Food Science and Technology, Shahre-Ghods Branch, Islamic Azad University, Tehran, Iran.
[3] Department of Food Hygiene, Science and Research Branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

Original Article

Article history:
Received 28 August 2023
Revised 16 November 2023
Accepted 04 December 2023
Available online 20 January 2024

Keywords:
Quinoa Flour
Gellan Gum
Low-Fat Hamburger
Antioxidant

ABSTRACT

There is growing interest in incorporating plant- and bacteria-derived ingredients with unique nutritional benefits for product reformulation. This study investigated the impact of quinoa flour and gellan gum substitution on low-fat hamburgers' physicochemical and sensory characteristics. The objective was to evaluate the effects of quinoa flour and gellan gum on low-fat hamburgers' physicochemical and sensory properties. Five hamburger samples (50 g each) were formulated with varying quinoa flour and gellan gum levels. Physicochemical analyses were performed, including moisture, protein, fat, ash, and carbohydrate content. Antioxidant activity, measured by pH and thiobarbituric acid index, was assessed on days 1, 14, and 28. Sensory evaluation encompassed color assessment, texture profile analysis, and a hedonic consumer test. Increasing quinoa flour and gellan gum levels synergistically decreased the thiobarbituric acid index compared to the control sample. Texture profile analysis revealed no significant differences in hardness, adhesion, elasticity, or chewiness among the samples. Likewise, no significant sensory differences were observed. The incorporation of quinoa flour in conjunction with gellan gum improved physicochemical properties, enhanced antioxidant activity, and maintained acceptable sensory attributes in low-fat hamburgers. Sample E3 (67% lean minced meat, 0% soy flour, 0.1% quinoa flour, 0.5% gellan gum, 14.5% fat) exhibited the most desirable characteristics. In contrast, sample A1 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0% gellan gum, 0.15% fat) was the least favorable compared to the control.

1. Introduction

Beef burgers have become a staple worldwide, appreciated for their flavor, versatility, and convenience. However, this widespread popularity is accompanied by growing concerns regarding diet-related diseases. Numerous studies have linked excessive consumption of red meat, particularly processed meats like hamburgers, to an increased risk of heart disease, stroke, type 2 diabetes, and certain cancers. Consequently, there is a pressing need for innovative and healthier alternatives that can satisfy consumer cravings without compromising health (1-3). Consumers are increasingly interested in functional products with lower fat content (4-7). Research has demonstrated the potential of using various alternatives, including hydrocolloids such as carrageenan, agar, and alginate (8) and microbial gums like xanthan, cellulose, and inulin (9). Additionally, various vegetable ingredients-such as seed gums, guar, starches, processed plant compounds (wheat bran, crops), soy-based products, bran and oat fiber, citrus fiber, and plant seeds-have been explored for their functional properties (10). Furthermore, esterified vegetable oils, nuts, and other compounds have shown potential benefits (11, 12). Quinoa, a grain-like seed native to the Andean region of South America, has recently emerged as a global superfood. Its remarkable adaptability is a significant factor in this surge in popularity. Unlike many crops that struggle in harsh environments, quinoa thrives in high altitudes, poor soil conditions, and with minimal water. This

*Corresponding author: Department of Food Science and Technology, Science and Research Branch, Islamic Azad University, Tehran, Iran.

E-mail address: dr.h.ahari@gmail.com (Hamed Ahari).

resilience positions it as a promising candidate for sustainable agriculture in a world confronting climate change and resource scarcity (13-15). In addition to its environmental benefits, quinoa is a valuable source of dietary fiber, a crucial component often lacking in gluten-free diets (16). Gellan gum, an extracellular polysaccharide produced by *Pseudomonas elodea*, is a fat substitute due to its water absorption properties (17, 18). This study investigates the combined effects of quinoa flour and gellan gum on low-fat hamburgers' physicochemical and organoleptic properties. By reducing lipid peroxidation, we aspire to develop a low-fat product suitable for inclusion in community food programs.

2. Materials and methods

2.1. Sample preparation

Sample preparation was conducted following the method described by Özer and Secen (19). Five hamburger samples (50 g each) were prepared as detailed in Supplementary Table 1. Each sample was shaped to a diameter of 90 mm and a thickness of 1 cm, then stored at -18 °C for further analyses.

2.2. Texture profile analysis (TPA)

Texture profile analysis (TPA) was performed on cooked samples using a texture analyzer (Brookfield, CT3, Middleboro, MA, United States) according to the protocols established by Özer and Secen (19) and Totosaus and Perez-Chabela (20). The parameters measured included hardness (N), adhesiveness (Ns), springiness, cohesiveness, and resilience. Cooked hamburger samples were cut into cubes (1×1×1 cm), equilibrated to room temperature (20 °C), and wrapped in plastic film for TPA. Test conditions were as follows: an aluminum rectangular probe (5 cm × 4 cm); test speed of 5 mm/s; pre-test speed of 2 mm/s; post-test speed of 1 mm/s; 70% compression; and a 25 kg load cell. Three replicate measurements were conducted for each sample per treatment the following day.

2.3. Instrumental color test

The color of the samples was assessed after overnight refrigeration using a HunterLab colorimeter (Color Flex, USA). The color test was based on the Commission International d'Eclairage LAB (CIELAB) system, with parameters including L* (L* = 0/black and L* = 100/white), a* (–a* = green and +a* = red), and b* (–b* = blue and +b* = yellow). Color parameters were measured at 15 locations on each hamburger sample surface immediately after production.

2.4. Chemical experiments

The moisture, protein, fat, ash, and total carbohydrates analyses were conducted according to the methods outlined in the National Standard of Frozen Raw Hamburger-Features and Test Methods No. 2304 (National Standard of Iran, No. 2304).

2.5. Lipid oxidation test

The thiobarbituric acid reactive substances (TBARS) test was performed using the method described by Zeb and Ullah (21). Reagents included thiobarbituric acid (TBA) (99%), tetra butyl ammonium (MDA) (96%), methanol (99.8%), glacial acetic acid (99%), and deionized water. To extract hamburger fat, 10 g of the sample was mixed with 20 mL of 10% trichloroacetic acid using a homogenizer. The resulting mixture was centrifuged at 1800 rpm for 30 min, and the solution was filtered through Whatman filter paper. Two mL of the filtered solution was then diluted with 2 mL of TBA reagent solution and placed in a water bath at 97 °C for 20 min. After cooling rapidly, the absorbance was measured at 532 nm using a spectrophotometer (Jenway, Germany). A standard curve was constructed based on tetrametoxypropane, and results were expressed as mg of malondialdehyde per kg of the sample. The experiment was conducted on the 1st, 14th, and 28th days, with three replicates.

2.6. pH Measurement

The pH meter was calibrated with buffer solutions (pH 4.01 and 7.00). The electrode was inserted directly into different areas of each sample, with the mean value reported as the final pH (Iranian National Standard, No. 2304). This assessment was conducted on the 1st, 14th, and 28th days, using a Jenway instrument (UK), with three replicates each time each time.

2.7. Sensory analysis

Sensory evaluation was conducted following the Sanful (22) method. A 5-factor hedonic questionnaire was utilized to assess the hamburger samples' color, aroma, and flavor, which were cooked before evaluation. The test was performed in three replicates on the day following production.

2.8. Statistical analysis

Statistical data analysis was performed using the One-Way ANOVA test, with Duncan's multiple range test applied for mean comparisons. All data are presented as mean ± standard deviation. Results were analyzed using SPSS v. 22 (SPSS Inc.) software, and graphical representations were created using Excel 2013 software. A p-value of <0.05 was considered statistically significant.

3. Results

3.1. Chemical composition

The moisture, protein, fat, ash, and carbohydrate content of hamburger samples containing varying levels of quinoa flour and gellan gum exhibited significant differences ($p<0.05$). Sample A1 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0% gellan gum, 0.15% fat) had the highest moisture content, while samples E2 (67% lean minced meat,

0% soy flour, 0.1% quinoa flour, 0.1% gellan gum, 14.9% fat) and E3 (67% lean minced meat, 0% soy flour, 0.1% quinoa flour, 0.5% gellan gum, 14.5% fat) showed the lowest moisture levels ($p<0.05$). In terms of protein content, sample E3 displayed the highest value, while the control sample (70% lean minced meat, 0.07% soy flour, 0% quinoa flour, 0% gellan gum, 0.15% fat) exhibited the lowest ($p<0.05$). Fat content varied significantly, with the control sample having the highest fat content and sample E3 the lowest ($p<0.05$). Ash content also showed significant variation, with sample E3 recording the highest and the control sample the lowest ($p<0.05$). Carbohydrate content differed significantly, with sample E1 (67% lean minced meat, 0% soy flour, 0.1% quinoa flour, 0% gellan gum, 0.15% fat) having the highest level. However, a discrepancy was noted in the fat content reporting for the control sample, requiring further verification ($p<0.05$). Detailed results for moisture, protein, fat, ash, and carbohydrate content are presented in Table 1.

Table.1. Results of the physicochemical (moisture, protein, fat, ash, and carbohydrates) tests of hamburger samples containing different amounts of quinoa flour and gellan gum.

Treatment	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrates (%)
C	62.12 ± 0.10^{c}	27.84 ± 0.10^{j}	$15.40\pm0.10^{a*}$	3.78 ± 0.10^{g}	9.20 ± 0.10^{i}
A1	62.36 ± 0.25^{a}	29.05 ± 0.25^{i}	15.06±0.25d	3.66 ± 0.25^{h}	10.15 ± 0.25^{h}
A2	62.28 ± 0.50^{b}	29.55 ± 0.50^{h}	14.93 ± 0.50^{e}	4.01 ± 0.50^{f}	10.78 ± 0.50^{g}
A3	62.12 ± 0.20^{c}	29.98 ± 0.20^{g}	14.59 ± 0.20^{h}	4.38 ± 0.20^{e}	11.09 ± 0.20^{f}
B1	62.90 ± 0.10^{d}	31.67 ± 0.10^{f}	15.14 ± 0.10^{c}	4.11 ± 0.10^{f}	12.83 ± 0.10^{e}
B2	62.82 ± 0.25^{e}	31.90 ± 0.25^{e}	14.89 ± 0.25^{f}	4.57 ± 0.25^{e}	13.19 ± 0.25^{c}
B3	62.79 ± 0.50^{e}	32.22 ± 0.50^{d}	14.54 ± 0.50^{i}	4.86 ± 0.50^{d}	13.4 ± 0.50^{b}
E1	0.20 ± 62.31^{f}	32.75 ± 0.20^{c}	15.21 ± 0.20^{b}	5.29 ± 0.20^{c}	14.53 ± 0.20^{a}
E2	62.66 ± 0.10^{g}	32.78 ± 0.10^{b}	14.83 ± 0.10^{g}	5.60 ± 0.10^{b}	13.00 ± 0.10^{d}
E3	62.43 ± 0.25^{h}	32.95 ± 0.25^{a}	14.51 ± 0.25^{j}	5.93 ± 0.25^{a}	12.83 ± 0.25^{e}

*Means within a row with the same lowercase letters are not significantly different at $p<0.05$.

3.2. pH value

Analysis of variance indicated a significant effect of treatment on the pH of hamburger samples containing different levels of quinoa flour and gellan gum across all three time points ($p<0.05$). Mean comparisons showed that sample E3 (67% lean minced meat, 0% soy flour, 0.1% quinoa flour, 0.5% gellan gum, 14.5% fat) consistently exhibited the highest pH throughout days 1, 14, and 28 ($p<0.05$). The lowest pH levels varied by time point: they were observed in samples A1 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0% gellan gum, 0.15% fat) and A2 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0.1% gellan gum, 14.9% fat) on days 14 and 28, and in sample A3 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0.5% gellan gum, 14.5% fat) on day 28 ($p<0.05$).

Table.2. pH of hamburger samples containing different amounts of quinoa flour and gellan gum.

Treatment	Storage time (Days)		
	1st day	14th day	28th day
C	5.92 ± 0.19^{eA}	5.92 ± 0.32^{eA}	5.92 ± 0.22^{fA}
A1	5.67 ± 0.09^{gC}	5.74 ± 0.19^{gB}	5.78 ± 0.06^{gA}
A2	5.68 ± 0.29^{gC}	5.70 ± 0.12^{gB}	5.77 ± 0.19^{gA}
A3	5.72 ± 0.09^{fA}	5.76 ± 0.09^{fA}	5.72 ± 0.10^{hA}
B1	6.03 ± 0.22^{dC}	6.12 ± 0.46^{bD}	6.16 ± 0.16^{eA}
B2	6.08 ± 0.09^{cC}	6.15 ± 0.09^{cB}	6.20 ± 0.10^{dA}
B3	6.10 ± 0.09^{cC}	6.19 ± 0.09^{bC}	6.24 ± 0.10^{cA}
E1	6.27 ± 0.22^{bC}	6.31 ± 0.46^{bB}	6.35 ± 0.16^{bA}
E2	6.28 ± 0.09^{bC}	6.32 ± 0.09^{cB}	6.38 ± 0.10^{aA}
E3	6.32 ± 0.09^{cA}	6.36 ± 0.09^{aB}	6.41 ± 0.10^{aA}

*Means within a row with the same lowercase letters are not significantly different at $p<0.05$.

Interestingly, the pH of all samples, except for the control and A3, increased significantly over time ($p<0.05$). Detailed results of the pH analysis are presented in Table 2.

3.3. TBARS content

Analysis of variance indicated no significant effect of treatment on the thiobarbituric acid index (TBARS) of hamburger samples with different levels of quinoa flour and gellan gum ($p>0.05$). However, mean comparisons showed that sample A1 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0% gellan gum, 0.15% fat) consistently exhibited the highest TBARS value across all three-time points (1st, 14th, and 28th days). In contrast, the lowest TBARS value was observed in sample E3 (67% lean minced meat, 0% soy flour, 0.1% quinoa flour, 0.5% gellan gum, 14.5% fat) ($p<0.05$). Additionally, the TBARS value for all samples, except for the control sample, significantly increased over time. Detailed results of the TBARS analysis are provided in Table 3.

Table.3. Thiobarbituric index of hamburger samples containing different amounts of quinoa flour and gellan gum.

Treatment	Storage time (Days)		
	1st day	14th day	28th day
C	2.67 ± 0.19^{bC}	2.81 ± 0.32^{bB}	2.94 ± 0.22^{bA}
A1	2.73 ± 0.09^{aC}	2.84 ± 0.19^{aB}	2.95 ± 0.06^{aA}
A2	2.64 ± 0.29^{cC}	2.78 ± 0.12^{cB}	2.89 ± 0.19^{dA}
A3	2.61 ± 0.09^{dC}	2.75 ± 0.09^{dB}	2.78 ± 0.10^{eA}
B1	2.53 ± 0.22^{eC}	2.67 ± 0.46^{eB}	2.70 ± 0.16^{dA}
B2	2.48 ± 0.09^{eF}	2.49 ± 0.09^{fB}	2.66 ± 0.10^{eA}
B3	2.35 ± 0.09^{gC}	2.43 ± 0.09^{gB}	2.56 ± 0.10^{fA}
E1	2.08 ± 0.22^{hC}	2.17 ± 0.46^{hB}	2.28 ± 0.16^{gA}
E2	1.77 ± 0.09^{iC}	1.89 ± 0.09^{iB}	2.05 ± 0.10^{hA}
E3	1.40 ± 0.09^{jC}	1.55 ± 0.09^{jB}	1.71 ± 0.10^{iA}

*Means within a row with the same lowercase letters are not significantly different at $p<0.05$.

3.4. Color analysis (L, a*, b*)*

Analysis of variance indicated no significant effect of treatment on the color parameters L* (lightness), a*

(redness/greenness), and b* (yellowness/blueness) among hamburger samples incorporating different levels of quinoa flour and gellan gum ($p > 0.05$). However, mean comparisons revealed noticeable variations in color components across the samples. Samples B3 (67% lean minced meat, 0% soy flour, 0.05% quinoa flour, 0.5% gellan gum, 14.5% fat) and E2 (67% lean minced meat, 0% soy flour, 0.1% quinoa flour, 0.1% gellan gum, 14.9% fat) exhibited the highest L* values, indicating the lightest color. Conversely, the control sample (70% lean minced meat, 0.07% soy flour, 0% quinoa flour, 0% gellan gum, 0.15% fat), A1 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0% gellan gum, 0.15% fat), and E1 (67% lean minced meat, 0% soy flour, 0.1% quinoa flour, 0% gellan gum, 0.15% fat) displayed the lowest L* values, indicating a darker appearance. For the a* parameter (redness/greenness), samples B3 and A3 (74% lean minced meat, 0% soy flour, 0.03% quinoa flour, 0.5% gellan gum, 14.5% fat) exhibited the highest values, suggesting a more reddish hue. The control sample, E1, and another mention of E1 (which appears to be a typographical error, requiring data verification) had the lowest a* values, indicating a more greenish tint. In terms of the b* parameter (yellowness /blueness), sample B3 again ranked highest, reflecting a more yellow color. The control sample, A1 and E1, had the lowest b* values, suggesting a bluish tone. Detailed results of the color component analysis are presented in Table 4.

Table.4. Results of the color parameters of hamburger samples containing different amounts of quinoa flour and gellan gum.

Treatment	L*	a*	b*
C	51.55±0.10^{e}	11.49±0.10^{cd}	9.09±0.10^{cd}
A1	53.73±0.25^{e}	15.07±0.25^{b}	8.74±0.25^{cd}
A2	57.57±0.50^{d}	13.21±0.50^{bc}	10.11±0.5^{bcd}
A3	57.68±0.20^{d}	17.96±0.20^{a}	8.55±0.20^{d}
B1	56.88±0.10^{d}	12.84±0.10^{bcd}	10.26±0.10^{bcd}
B2	59.78±0.25^{cd}	12.78±0.25^{bcd}	10.27±0.25^{bcd}
B3	66.04±0.50^{a}	17.25±0.50^{a}	13.02±0.50^{a}
E1	51.66±0.20^{e}	10.75±0.20^{d}	8.97±0.20^{cd}
E2	63.07±0.10^{ab}	14.09±0.10^{b}	12.02±0.10^{i}
E3	62.48±0.25^{bc}	14.53±0.25^{b}	11.45±0.25^{abc}

*Means within a row with the same lowercase letters are not significantly different at $p<0.05$.

3.5. Texture parameters

Analysis of variance revealed no significant effect ($p>0.05$) of treatment on the textural properties (hardness, adhesion, elasticity, and fragility) or sensory characteristics (color, odor, taste, and overall acceptance) of hamburger samples formulated with varying levels of quinoa flour and gellan gum. Detailed results of these analyses are presented in Table 5.

Table.5. Results of the TPA (Hardness, adhesion, elasticity and fragility) and sensory properties (Taste, color, smell and overall acceptance) of hamburger samples containing different amounts of quinoa flour and gelan gum.

	Hardness	Adhesion	Elasticity	Fragility	Taste	Color	Smell	Overall acceptance
C	4.80±0.10^{h}	0.94±0.10^{a}	0.51±0.10^{c}	0.13±0.00^{b}	3.22±0.10^{b}	3.66±0.10^{b}	2.66±0.10^{b}	3.66±0.10^{a}
A1	5.31±0.25^{a}	0.85±0.25^{b}	0.59±0.25^{b}	3.57±0.00^{a}	4.66±0.57^{a}	4.66±0.25^{a}	2.66±0.25^{b}	3.66±0.25^{a}
A2	1.60±0.50^{d}	0.09±0.50^{c}	1.00±0.50^{a}	0.01±0.00^{i}	4.66±0.57^{a}	4.66±050^{a}	3.66±0.50^{b}	4.66±0.50^{a}
A3	1.49±0.20^{f}	0.03±0.20^{f}	1.00±0.20^{a}	0.05±0.00^{c}	4.66±0.57^{a}	4.66±0.20^{a}	3.66±0.20^{b}	4.66±0.20^{a}
B1	1.23±0.10^{g}	0.05±0.10^{e}	1.00±0.10^{a}	0.03±0.00^{d}	4.66±0.57^{a}	4.66±0.10^{a}	4.66±0.10^{b}	4.66±0.10^{a}
B2	1.85±0.25^{b}	0.05±0.25^{d}	1.00±0.25^{a}	0/00±۰/۰۰^{j}	4.66±0.57^{a}	4.66±0.25^{a}	4.66±0.25^{a}	4.66±0.25^{a}
B3	1.70±0.50^{b}	-0.25±0.50^{j}	1.00±0.50^{a}	0.002±0.00^{e}	4.66±0.57^{a}	4.66±0.50^{a}	4.66±0.50^{a}	4.66±0.50^{a}
E1	1.52±0.20^{c}	-0.09±0.20^{g}	1.00±0.20^{a}	0.01±0.00^{h}	4.66±0.57^{a}	3.66±0.20^{b}	4.66±0.20^{a}	3.66±0.20^{a}
E2	0.56±0.10^{j}	-0.10±0.10^{h}	1.00±0.10^{a}	0.01±0.00^{g}	4.66±0.57^{a}	3.66±0.10^{b}	4.66±0.10^{a}	3.66±0.10^{b}
E3	0.69±0.25^{i}	-0.16±0.25^{i}	1.00±0.25^{a}	0.01±0.05^{f}	4.66±0.57^{a}	3.66±0.25^{b}	4.66±0.25^{a}	3.66±0.25^{b}

*Means within a row with the same lowercase letters are not significantly different at $p<0.05$.

4. Discussion

This study investigated the influence of quinoa flour and gellan gum substitution on low-fat hamburgers' physicochemical and sensory characteristics. Gellan gum, a versatile hydrocolloid, has diverse applications in food stabilization, functioning as an emulsifier, binder, gelling agent, and thickener in products such as dairy desserts, jams, and fabricated foods (18, 23-28). Research indicates that replacing beef fat with gel emulsions containing gellan gum can enhance emulsion stability and potentially confer health benefits (29, 30, 31). Our findings revealed that increasing quinoa flour content led to a rise in moisture content, while gellan gum alone exhibited a moisture-reducing effect. Previous studies support this observation, indicating that gellan gum enhances water-binding capabilities within meat products, potentially reducing production costs (20). Additionally, higher percentages of quinoa flour and gellan gum increased protein content. Conversely, fat content decreased as the proportion of these substitutes increased. Similarly, ash content demonstrated an upward trend with increasing levels of both ingredients. These results align with findings by Shokry (32), who reported elevated protein, mineral, and moisture content in hamburgers partially substituted with soy flour. Comparable trends of increased protein and ash content in meat products fortified with vegetable components have been documented in other studies (33, 34). The effect of quinoa flour on pH was contingent upon its interaction with gellan gum. A decrease in pH compared to the control was observed at lower quinoa flour concentrations and in the absence of gellan gum synergy. However, when used synergistically and at higher concentrations, the pH increased compared to the control. Existing literature suggests that their inherent acidity influences the change in pH upon the addition of vegetable sources. Plant-based ingredients with acidic pH profiles typically lower the pH of meat products as their inclusion level rises (35, 36). Interestingly, the thiobarbituric acid index, a marker of lipid oxidation, significantly increased over time in all samples except for the control (day 1 samples). Research suggests substituting soy

flour with quinoa flour in hamburgers can enhance antioxidant effects. The observed increase in TBARS might be linked to specific oxidizing systems and their interactions within the meat matrix (37). Color analysis revealed that the combined use of quinoa flour and gellan gum resulted in samples with greater brightness than the control; however, the red color component decreased with the addition of gellan gum, weakening the color synergy. Conversely, the green color component increased with higher levels of both ingredients. Similar observations have been reported in other studies, where different flours used in meat products resulted in color variations primarily due to pigment dilution by the flours rather than their inherent colors (38, 39). Texture Profile Analysis (TPA) indicated no significant effect of treatment on hardness, adhesion, elasticity, or fragility. However, the non-significant differences revealed a trend where increased quinoa flour content without gellan gum increased textural firmness. Although not statistically significant, the synergistic effect of quinoa flour and gellan gum appeared to decrease hardness, adhesion, and tissue fragility while enhancing elasticity. The underlying reasons for these observations may be related to quinoa flour components' hydrochemical and physical properties (40). Similar trends have been noted with the incorporation of other ingredients, such as oatmeal, Nata de coco, and rice bran, in meat products (41-43). Sensory evaluation, consistent with TPA results, demonstrated no significant differences in color, odor, taste, or overall acceptability.

5. Conclusion

This study underscores the importance of optimizing the amounts of quinoa flour and gellan gum to achieve superior product quality. While small quantities of quinoa flour without sufficient gellan gum synergy may compromise product characteristics, higher levels used synergistically with gellan gum enhance physicochemical properties, confer significant antioxidant effects, and maintain acceptable sensory attributes. Considering the potential benefits for individuals with celiac disease (gluten-free) and the overall product improvements achieved through tissue enhancement and fat reduction, further research to optimize the synergistic application of quinoa flour and gellan gum is warranted.

References

1. Gordon-Larsen P, Guilkey DK, Popkin BM. An economic analysis of community-level fast food prices and individual-level fast food intake: a longitudinal study. *Health & Place*. 2011;17(6):1235-41.
2. Bozbulut R, Sanlier N. Promising effects of β-glucans on glycaemic control in diabetes. *Trends in Food Science & Technology*. 2019;83:159-66.
3. Ho HV, Sievenpiper JL, Zurbau A, Mejia SB, Jovanovski E, Au-Yeung F, et al. The effect of oat β-glucan on LDL-cholesterol, non-HDL-cholesterol and apoB for CVD risk reduction: a systematic review and meta-analysis of randomized-controlled trials. B*ritish Journal of Nutrition*. 2016;116(8):1369-82.
4. Brewer MS. Reducing the fat content in ground beef without sacrificing quality: A review. *Meat Science*. 2012;91(4):385-95.
5. Drewnowski A, Almiron-Roig E. 11 Human perceptions and preferences for fat-rich foods. Fat detection: Taste, texture, and post ingestive effects. 2009;23:265.
6. Ognean CF, Darie N, Ognean M. Fat replacers: review. Journal of *Agroalimentary Processes and Technologies*. 2006;12(2):433-42.
7. Ravisankar P, Reddy AA, Nagalakshmi B, Sai O, Kumar BV, Anvith PS. The comprehensive review on fat soluble vitamins. *IOSR Journal of Pharmacy*. 2015;5(11):12-28.
8. Ahmed P, Miller M, Lyon C, Vaughters H, Reagan J. Physical and sensory characteristics of low-fat fresh pork sausage processed with various levels of added water. *Journal of Food Science*. 1990;55(3):625-8.
9. Kaur N, Gupta AK. Applications of inulin and oligofructose in health and nutrition. *Journal of Biosciences*. 2002;27(7):703-14.
10. Sobczak M, Lachowicz K, Żochowska-Kujawska J, Gajowiecki L, Klemke A. An assessment of fat substitution with buckwheat seed preparation on the quality of comminuted meat products. *Food Science and Technology*. 2006;9(4):13.
11. Morin L, Temelli F, McMullen L. Physical and sensory characteristics of reduced-fat breakfast sausages formulated with barley β-glucan. *Journal of Food Science*. 2002;67(6):2391-6.
12. Vural H. Effect of replacing beef fat and tail fat with interesterified plant oil on quality characteristics of Turkish semi-dry fermented sausages. *European Food Research and Technology*. 2003;217(2):100-3.
13. James LEA. Quinoa (Chenopodium quinoa Willd.): composition, chemistry, nutritional, and functional properties. *Advances in Food and Nutrition Research.* 2009;58:1-31.
14. Abderrahim F, Huanatico E, Segura R, Arribas S, Gonzalez MC, Condezo-Hoyos L. Physical features, phenolic compounds, betalains and total antioxidant capacity of coloured quinoa seeds (Chenopodium quinoa Willd.) from Peruvian Altiplano. *Food Chemistry*. 2015;183:83-90.
15. Wang S, Zhu F. Formulation and quality attributes of quinoa food products. *Food and Bioprocess Technology*. 2016;9(1):49-68.
16. Belton PS, Taylor JR. Pseudocereals and less common cereals: grain properties and utilization potential. *Springer Science & Business Media*; 2002.
17. Warren H, in het Panhuis M. Highly conducting composite hydrogels from gellan gum, PEDOT: PSS and carbon nanofibres. *Synthetic Metals*. 2015;206:61-5.
18. Zia KM, Tabasum S, Khan MF, Akram N, Akhter N, Noreen A, et al. Recent trends on gellan gum blends with natural and synthetic polymers: A review. *International Journal of Biological Macromolecules*. 2018;109:1068-87.
19. Özer CO, Secen SM. Effects of quinoa flour on lipid and protein oxidation in raw and cooked beef burger during long-term frozen storage. *Food Science and Technology.* 2018;38:221-7.
20. Totosaus A, Perez-Chabela ML. Textural properties and microstructure of low-fat and sodium-reduced meat batters formulated with gellan gum and dicationic salts. *LWT-Food Science and Technology*. 2009;42(2):563-9.
21. Zeb A, Ullah F. A simple spectrophotometric method for the determination of thiobarbituric acid reactive substances in fried fast foods. *Journal of Analytical Methods in Chemistry*. 2016;2016.
22. Sanful RE. Organoleptic and nutritional analysis of taro and wheat flour composite bread. *World Journal of Dairy and Food Sciences*. 2011;6(2):175-9.
23. Kiani H, Mousavi M, Razavi H, Morris E. Effect of gellan, alone and in combination with high-methoxy pectin, on the structure and stability of doogh, a yogurt-based *Iranian drink. Food Hydrocolloids*. 2010;24(8):744-54.
24. Rosas-Flores W, Ramos-Ramírez EG, Salazar-Montoya JA. Microencapsulation of *Lactobacillus helveticus* and *Lactobacillus delbrueckii* using alginate and gellan gum. *Carbohydrate Polymers*. 2013;98(1):1011-7.
25. Danalache F, Beirão-da-Costa S, Mata P, Alves VD, Moldao-Martins M. Texture, microstructure and consumer preference of mango bars jellified with gellan gum. *LWT-Food Science and Technology*. 2015;62(1):584-91.
26. Zhang N, Xu J, Gao X, Fu X, Zheng D. Factors affecting water resistance of alginate/gellan blend films on paper cups for hot drinks. *Carbohydrate Polymers*. 2017;156:435-42.
27. de Oliveira Cardoso VM, Cury BSF, Evangelista RC, Gremião MPD. Development and characterization of cross-linked gellan gum and retrograded starch blend hydrogels for drug delivery applications. *Journal*

of the Mechanical Behavior of Biomedical Materials. 2017;65:317-33.
28. Bonifacio MA, Gentile P, Ferreira AM, Cometa S, De Giglio E. Insight into halloysite nanotubes-loaded gellan gum hydrogels for soft tissue engineering applications. *Carbohydrate Polymers.* 2017;163:280-91.
29. Karthika J, Vishalakshi B, Naik J. Gellan gum–graft–polyaniline—An electrical conducting biopolymer. *International Journal of Biological Macromolecules.* 2016;82:61-7.
30. Dolan LC, Matulka RA, LeBeau AL, Boulet JM. Two new nontoxic, non-pathogenic strains of Sphingomonas elodea for gellan gum production. *Regulatory Toxicology and Pharmacology*. 2016;78:37-44.
31. Serdaroğlu M, Nacak B, Karabıyıkoğlu M, Keser G. Effects of partial beef fat replacement with gelled emulsion on functional and quality properties of model system meat emulsions. *Korean Journal for Food Science of Animal Resources*. 2016;36(6):744.
32. Shokry AM. The usage of quinoa flour as a potential ingredient in production of meat burger with functional properties. *Middle East Journal of Applied Sciences*. 2016;6(4):1128-37.
33. Hu G, Yu W. Effect of hemicellulose from rice bran on low-fat meatballs chemical and functional properties. *Food Chemistry*. 2015;186:239-43.
34. Talukder S. Effect of dietary fiber on properties and acceptance of meat products: a review. *Critical Reviews in Food Science and Nutrition*. 2015;55(7):1005-11.
35. Aleson-Carbonell L, Fernández-López J, Sendra E, Sayas-Barberá E, Pérez-Alvarez JA. Quality characteristics of a non-fermented dry-cured sausage formulated with lemon albedo. *Journal of the Science of Food and Agriculture*. 2004;84(15):2077-84.
36. Dzudie T, Scher J, Hardy J. Common bean flour as an extender in beef sausages. *Journal of Food Engineering*. 2002;52(2):143-7.
37. Lund MN, Heinonen M, Baron CP, Estevez M. Protein oxidation in muscle foods: A review. *Molecular Nutrition & Food Research*. 2011;55(1):83-95.
38. Alakali J, Irtwange S, Mzer M. Quality evaluation of beef patties formulated with bambara groundnut (*Vigna subterranean* L.) seed flour. *Meat Science*. 2010;85(2):215-23.
39. Shahiri Tabarestani H, Mazaheri Tehrani M. Optimization of physicochemical properties of low-fat hamburger formulation using blend of soy flour, split-pea flour and wheat starch as part of fat replacer system. *Journal of Food Processing and Preservation*. 2014;38(1):278-88.
40. Ergezer H, Akcan T, Serdaroğlu M. The effects of potato puree and bread crumbs on some quality characteristics of low-fat meatballs. *Korean Journal for Food Science of Animal Resources*. 2014;34(5):561.
41. Choi YS, Choi JH, Han DJ, Kim HY, Lee MA, Kim HW, et al. Effects of rice bran fiber on heat-induced gel prepared with pork salt-soluble meat proteins in a model system. *Meat Science*. 2011;88(1):59-66.
42. Lin K, Lin H. Quality characteristics of Chinese-style meatball containing bacterial cellulose (Nata). *Journal of Food Science*. 2004;69(3):SNQ107-SNQ11.
43. Yang H-S, Choi S-G, Jeon J-T, Park G-B, Joo S-T. Textural and sensory properties of low-fat pork sausages with added hydrated oatmeal and tofu as texture-modifying agents. *Meat Science*. 2007;75(2):283-9.