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Production and Evaluation of Gluten-Free Pasta and Pan Bread from *Spirulina* Algae Powder and Quinoa Flour

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Abstract: This study was carried out to evaluate semolina flour (SF), wheat flour (WF), quinoa (*Chenopodium quinoa* Willd.) flour (QF), *spirulina* algae powder (SAP) and their blends for production of gluten-free pasta and bread suitable for celiac patients. Pasta made of 100% semolina and pan bread made of 100% WF were prepared for comparison with pasta and pan bread from QF and blends with SAP at different levels (5, 10 and 15%). The chemical composition, rheological properties, color attributes, cooking quality, baking quality, sensory properties and texture analysis of the pasta and pan bread were investigated. SAP was added to QF at 5, 10 and 15% levels. The results show that SAP is marked by higher protein (63.65%), fat (6.18%), and ash (12.50%) contents. Thus, raising the mixing level of SAP with QF resulted in an increase in the nutritional value of pasta and pan bread. Moreover, these high-protein products improved basal metabolic rate, preserved body muscle mass, and decreased body fat percentage. Farinograph characteristics demonstrated that water absorption, arrival time, dough development time, and stability grew as the ratio of SAP in QF increased. The addition of SAP to QF in increasing proportions from 5% to 15% decreased the elasticity and proportional number, while the extensibility and energy of the dough increased. Also, addition of SAP to QF at different levels (5 to 15%) decreased all viscoamylograph parameters except for the temperature of transition, which increased. In regard to cooking quality, all the pasta samples prepared by mixing SAP with QF had higher weight, volume, and cooking loss than the control. Additionally, while all samples of pasta and pan bread passed the sensory test, those that contained SAP had greater sensory qualities and nutritional value. These products are suitable for athletes and for patients with celiac disease and obesity.

Keywords: quinoa; *spirulina*; pasta; pan bread; cooking quality; baking quality; sensory evaluation; celiac patients; anthropometric parameters

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1. Introduction

The interest in making gluten-free bread is developing as a result of the increase in the demand for gluten-free products in recent years. In numerous studies, gluten-free flour (such as rice or corn flour) was utilized to make bakery products [1,2]. *Spirulina* is considered safe for consumption due to its beneficial components such as phycocyanin, β-carotene, xanthophyll pigments, α-tocopherol, and phenolic compounds. These substances contribute to the antioxidant activities of *spirulina*, as demonstrated in various in vitro and in vivo experiments [3]. Researchers have primarily concentrated on investigating the health impacts of *spirulina* as a dietary supplement for humans, highlighting its potential anti-cancer impact [4], hypolipidemic effect [5], and protective influence against diabetes and obesity [6,7]. Due to these benefits, *spirulina* is now regarded as a key component for creating nutritious food products [8,9].

Quinoa, a gluten-free pseudo-cereal, possesses several nutritional benefits. It is rich in fiber, proteins/peptides with high biological value, vital fatty acids (such as ω-3 and ω-6), vitamins, and minerals [10,11]. Moreover, quinoa exhibits starch properties similar to wheat, making it suitable for use in the bakery industry [12]. Incorporating quinoa flour in bakery products like bread and cookies has shown positive effects on their sensory characteristics [13]. From a nutritional standpoint, quinoa is considered a super grain, comparable with milk according to the World Health Organization. It boasts high levels of potassium, riboflavin, B6, niacin, and thiamin, as well as significant amounts of magnesium, zinc, copper, and manganese [14]. Consequently, quinoa flour, either by itself or when enriched with other gluten-free flour, serves as a healthy choice for individuals with celiac disease [15]. Traditional gluten-free breads and biscuits, predominantly made from rice or maize flour, tend to have low protein content and poor protein quality [16].

Additionally, other authors have carried out research using *spirulina* added to flour at various levels (2%, 2.5%, and 3%) [17]. In comparison to the control bread without *spirulina*, increased protein and minerals were found in the finished bread product. In another study, Achour et al. [18] produced enriched bread using 1% and 3% of microalga *spirulina*'s dry biomass. *Spirulina* enrichment boosted the bread's nutritional value (in terms of protein and ash). The values of the remaining nutrients (fat, crude fiber, and carbohydrates) remained almost unchanged.

Pasta is a widely consumed and popular food made from cereals [19]. However, pasta typically has a low protein content. Therefore, enriching pasta with *spirulina* powder to increase its protein content is an important approach to address protein deficiency in developing countries. By delivering food markets with a popular and affordable source of food that is rich in protein, this initiative can contribute to sustainable development and have high economic value.

Bread is a staple food in both developed and developing countries. For many years, wheat flour, derived from both hard and soft wheat classes, has been the primary ingredient in leavened bread due to its functional proteins [20]. However, efforts have been made to promote the use of composite flour, in which a portion of wheat flour is substituted with locally grown crops, in bread production. This approach helps to reduce the cost associated with using significant amounts of wheat [21]. For the above-mentioned reasons, the aim of this investigation was to produce gluten-free pasta and bread suitable for celiac patients with high nutritional value using quinoa flour (QF) and *spirulina* algae powder (SAP). This research also aimed to determine the effect of the addition of SAP to QF on the quality of samples by measuring several physical, chemical, nutritional, and sensory properties.

2. Materials and Methods

2.1. Materials

Spirulina algae powder (SAP) was obtained from Nourelhooda Co., Cairo, Egypt. The powder was packaged in a polypropylene bag with an aluminum layer and stored in cool, dry conditions away from sunlight until further processing of the pasta and pan bread. Quinoa seeds were obtained from the Field Crops Research Institute (FCRI), Agricultural Research Centre, Cairo, Egypt. Other necessary materials for the preparation of pasta and pan bread were purchased from the local market in Dokki, Cairo, Egypt.

2.2. Methods

2.2.1. Preparation of Quinoa Flour (QF)

Quinoa seeds were cleaned and washed thoroughly with running tap water, stirring continuously for approximately 1–2 min. The water was drained and the wet seeds were dried overnight in an air oven (Memmert UNE 400, Büchenbach, Germany) at 55 °C ± 1 °C. The dried quinoa seeds were then milled using a Quadrumat Junior flour mill. The resulting quinoa flour (QF) was packed into polyethylene bags and stored in a deep freezer at −18 °C until further use.

2.2.2. Blends Preparation

We conducted several preliminary tests, but the blends produced had adverse impacts on some quality attributes of the end product. Finally, we selected 5%, 10%, and 15% levels of SAP for further testing. When choosing these concentrations, we also considered the economics of the finished product in the market. Briefly, QF was blended with SAP to create different mixtures containing 0%, 5%, 10%, and 15% *spirulina* algae. All the samples were stored in airtight containers and kept at 3–5 °C until used.

2.2.3. Rheological Properties

The rheological properties of the doughs were evaluated using farinograph, extensograph, and amylograph tests following the methods outlined by AACC (2002) [22].

2.2.4. Preparation and Evaluation of Cooking Quality and Sensory Properties of Pasta

Pasta dough was prepared based on a 250 g flour recipe according to the procedure described by Hussein et al. [23]. The different blends of QF and SAP were combined and mixed to create a homogeneous mixture. The mixture was placed in a mixing bowl and mixed until the dough formed. The dough was then rounded into a ball shape, covered with plastic wrap, allowed to rest for 30 min, hand-kneaded for 1 min, divided into approximately 100 g portions, and formed using a pasta machine (Philips Pastamaker HR2357/05 Machine Corporation, Milan, Italy). The cooking quality of the pasta was evaluated by determining the weight, volume, and cooking loss after cooking, following the methods specified by AACC (2000) [22]. Cooked pasta samples were served to a panel of fifteen trained academic staff members who assessed the color, flavor, mouthfeel, elasticity, and overall acceptability using a 10-point hedonic scale (0 = dislike extremely; 5 = middle; 10 = like extremely) for each sensory characteristic [24].

2.2.5. Preparation and Evaluation of Baking Quality and Sensory Properties of Pan Bread

The production of pan bread was carried out at the pilot plant located at the National Research Centre (NRC) in Dokki, Egypt, following the procedures outlined by AACC (2005) [25]. The ingredients for the pan bread included 100 g mixed flour, 1.5 g instant active dry yeast, 1 g salt (sodium chloride), 5 g sugar (sucrose), 5 g shortening, and water (added to reach 500 Brabender Units of consistency). The dry ingredients were manually mixed and added to a mixing bowl. Shortening and water were then added, and the components were thoroughly mixed using an electric mixer. The resulting dough was divided, rounded, allowed to relax, molded, panned, and proofed in a fermentation cabinet. The proofed pieces were then baked in an electric oven, cooled, packed, and subjected to further analysis. The weight, volume, and specific volume of the bread samples were determined following the methods described by AACC (2005) [25]. The sensory properties of the pan bread samples were evaluated for taste, aroma, mouthfeel, crumb texture, crumb color, break and shred, crust color, and symmetry shape, using the method outlined in AACC (2005) [25].

2.2.6. Color Determinations

The objective evaluation of color for the raw materials and products (pasta and pan bread) was measured using a color difference meter and spectro-colorimeter. The Hunter a*, b*, and L* parameters were measured in reflection mode using the CIE lab color scale. The instrument was standardized with a white tile of Hunter Lab Colour Standard before each measurement.

2.2.7. Proximate Composition

The moisture, ash, crude protein, fat, and crude fiber contents of the raw materials and products (pasta and pan bread) were determined following the methods outlined by AOAC (2016) [26]. The carbohydrate content was calculated by difference, using the formula: Carbohydrates = 100 − (% protein + % fat + % ash + % crude fiber). The total carbohydrate content was calculated by difference as well.

2.2.8. Mineral Content

The contents of calcium (Ca), phosphorus (P), potassium (K), sodium (Na), iron (Fe), and zinc (Zn) in WF, SP, QF, pasta, and pan bread, respectively, were determined using the methods described by Ziemichód et al. [27].

2.2.9. Texture Properties of Pasta and Pan Bread

The textural characteristics of uncooked and cooked pasta samples and pan bread were assessed utilizing a texturometer (Brookfield model-CT3–10 kg, Middleborough, MA, USA) equipped with a fixture (TA-SBA). Various texture parameters such as hardness, deformation at hardness, hardness work, load at target, deformation at target, peak stress, fracturability, and fracture load drop-off were measured. The trigger load and test speed used were 9.00 N and 2.5 mm/s, respectively. The pasta samples were cylinder-shaped with the following dimensions: length of 30 mm, and a diameter of 50 mm.

2.2.10. Anthropometric Parameters Measurements

Body mass index, percentage body fat of the body weight, lean body mass and basal metabolic rate were measured using Geratherm Body Fitness (B-5010)—German [28] in the nutrition and food science department from November 2022 to February 2023. Volunteer female subjects aged 30 to 40 years consumed these products for four weeks in their diets without caloric restriction. The group who consumed the conventional pasta replaced the semolina flour-prepared pasta by the one prepared with 15% *spirulina* algae powder and 85% quinoa flour, while the second group consumed pan bread prepared from 15% *spirulina* algae powder and 85% quinoa flour to replace their normal daily consumption of baladi bread prepared from wheat flour. The participants had no change in their lifestyle.

2.2.11. Statistical Analysis

The obtained results were evaluated statistically using analysis of variance (ANOVA) and the least significant difference (LSD) test ($p < 0.05$).

3. Results and Discussion

3.1. The Chemical Composition

The proximate composition of the raw materials (SAP, QF, WF and SF), and various pasta and pan bread samples are provided in Table 1. *Spirulina* algae powder (SAP) exhibited a high protein content (63.65%), which was followed by fat (6.18%), ash (12.50%), and fiber (4.15%), and the least abundant nutrient was carbohydrate (13.52%). These findings are consistent with previous work conducted by [29–32] regarding the chemical composition of SAP.

Table 1. Proximate composition of raw materials (SAP, QF, WF and SF), pasta and pan bread (% on dry weight basis).

Samples	Moisture	Protein	Fat	Ash	Fiber	Carbohydrates
SAP	6.85 ^{d} ± 0.14	63.65 ^{a} ± 1.22	6.18 ^{b} ± 0.17	12.50 ^{a} ± 0.13	4.15 ^{a} ± 0.0.15	13.52 ^{d} ± 0.32
QF	10.52 ^{c} ± 0.01	15.60 ^{b} ± 0.06	6.65 ^{a} ± 0.03	3.60 ^{b} ± 0.03	4.05 ^{a} ± 0.02	70.10 ^{c} ± 0.04
WF	11.20 ^{b} ± 0.17	10.50 ^{d} ± 0.11	1.15 ^{d} ± 0.08	0.79 ^{c} ± 0.01	0.43 ^{c} ± 0.02	86.70 ^{a} ± 0.56
SF	11.85 ^{a} ± 0.09	13.11 ^{c} ± 0.10	1.58 ^{c} ± 0.05	0.82 ^{c} ± 0.04	0.75 ^{b} ± 0.01	83.74 ^{b} ± 0.82
LSD at 0.05	0.09427	0.88082	0.32932	0.43128	0.30274	0.39541

Table 1. *Cont.*

Samples	Moisture	Protein	Fat	Ash	Fiber	Carbohydrates
			Pasta			
100% SF	5.75 ^{d} ± 0.22	13.25 ^{e} ± 0.38	1.05 ^{d} ± 0.05	0.88 ^{e} ± 0.01	0.83 ^{e} ± 0.03	83.99 ^{a} ± 0.72
100% QF	6.15 ^{c} ± 0.05	15.92 ^{d} ± 0.13	5.35 ^{c} ± 0.08	3.22 ^{d} ± 0.13	3.88 ^{ab} ± 0.01	71.63 ^{b} ± 0.62
5% SAP + 95% QF	6.01 ^{cd} ± 0.03	18.95 ^{c} ± 0.07	5.18 ^{c} ± 0. 04	3.31 ^{c} ± 0.06	3.81 ^{b} ± 0.002	68.75 ^{c} ± 0.72
10% SAP + 90% QF	6.50 ^{b} ± 0.06	22.11 ^{b} ± 0.15	5.60 ^{b} ± 0.07	4.12 ^{b} ± 0.03	3.95 ^{ab} ± 0.005	64.22 ^{d} ± 0.59
15% SAP + 85% QF	6.86 ^{a} ± 0.11	25.25 ^{a} ± 0.13	5.79 ^{a} ± 0.08	4.62 ^{a} ± 0.07	4.02 ^{a} ± 0.06	60.32 ^{e} ± 0.69
LSD at 0.05	0.23661	0.40000	0.15186	0.08646	0.16151	0.17835
			Pan bread			
100% WF	34.11 ^{e} ± 0.17	10.86 ^{e} ± 0.76	6.58 ^{c} ± 0.43	2.11 ^{d} ± 0.24	0.50 ^{c} ± 0.06	79.95 ^{a} ± 2.68
100% QF	38.37 ^{d} ± 0.43	16.80 ^{d} ± 0.43	8.45 ^{b} ± 0.43	3.35 ^{c} ± 0.43	4.02 ^{b} ± 0.13	67.38 ^{b} ± 1.43
5% SAP + 95% QF	39.50 ^{c} ± 0.43	18.95 ^{c} ± 0.43	8.50 ^{b} ± 0.43	3.75 ^{c} ± 0.43	4.07 ^{ab} ± 0.19	64.73 ^{c} ± 1.05
10% SAP + 90% QF	41.70 ^{b} ± 0.43	21.90 ^{b} ± 0.43	8.60 ^{a} ± 0.43	4.20 ^{b} ± 0.43	4.09 ^{ab} ± 0.26	61.21 ^{d} ± 0.96
15% SAP + 85% QF	43.20 ^{a} ± 0.43	24.05 ^{a} ± 0.43	8.75 ^{a} ± 0.43	4.55 ^{a} ± 0.43	4.11 ^{a} ± 0.35	58.54 ^{e} ± 1.16
LSD at 0.05	0.14043	0.14212	0.18492	0.09687	0.07876	0.138/73

Where: SAP = *spirulina* algae powder; QF = quinoa flour; WF = wheat flour; SF = semolina flour. The values are the mean ± SD of three replicates. The values in the same column followed by different letters are significantly different ($p < 0.05$).

Quinoa flour (QF) contained 10.52% moisture, 15.60% crude protein, 6.65% ether extract (fat), 4.05% crude fiber, 1.2% total ash, and 70.10% carbohydrates. These results align with previous research by [33–35] regarding the chemical composition of QF.

The moisture, protein, fat, ash, fiber, and total carbohydrate contents of wheat flour (WF) and semolina flour (SF) ranged from 11.20% to 11.85%, 10.50% to 13.11%, 1.15% to 1.58%, 0.79% to 0.82%, 0.43% to 0.75%, and 83.74% to 86.70%, respectively. These results are consistent with those of previous research by Hussein et al. [36] concerning the chemical composition of WF and SF.

The addition of SAP to QF at different concentrations (0%, 5%, 10%, and 15%) enhanced the chemical composition of the prepared pasta. The protein, fat, ash, and fiber contents of the pasta samples increased with increasing SAP concentration. This indicates that the prepared pasta can serve as a functional food rich in protein and minerals, making it suitable for individuals with celiac disease. Previous studies by Lemes et al. [37], Pagnussatt et al. [38], Özyurt et al. [39], Batista et al. [40], and Uribe-Wandurraga et al. [41] have demonstrated that the addition of SAP (in the range of 1.5% to 6%) raises the protein and mineral levels in food products.

The chemical changes in pan bread resulting from the incorporation of different levels of SAP were also investigated. The protein, fat, ash, and fiber contents of the pan bread samples increased with increasing SAP addition. This can be attributed to the relatively higher protein, fat, ash, and fiber contents of SAP compared with those of wheat flour (WF). These findings are consistent with previous studies conducted by Selmo et al. [42], Shahbazizadeh et al. [43], and Gadallah et al. [44].

3.2. Mineral Contents of Raw Materials and Their Products

The mineral contents of raw materials and their products are given in Table 2. The results presented in Table 2 indicate high contents of the analyzed minerals in SAP, followed by QF, and then SF and WF. The mineral contents of the control sample (pasta made from 100% SF), pasta samples with 100% QF and QF substituted with SAP at 5, 10 and 15% levels were determined. These results indicate that the mineral concentration gradually increased across all samples. The rise in the amount of minerals from the control sample (100% SF) to 100% QF or QF supplemented with SAP at different levels (5 to 15%) could be related to the greater mineral content in QF and SAP. The same trend was observed in the pan bread control (100% WF), pan bread produced from 100% QF and QF supplemented with SAP at different levels (5, 10 and 15%). These outcomes are well-aligned with those of Alvarez-Jubete et al. [45], Stikic et al. [13] and Hussein et al. [23].

Table 2. Mineral contents of raw materials, pasta and pan bread (mg/100 g).

Samples	Ca	P	K	Na	Fe	Zn
SAP	165.1 ^{a} ± 2.15	790.42 ^{a} ± 7.12	165.1 ^{d} ± 3.11	762 ^{b} ± 5.10	56.6 ^{a} ± 1.15	4.5 ^{b} ± 0.35
QF	82.0 ^{b} ± 1.11	518.0 ^{b} ± 5.15	681 ^{a} ± 4.15	1428.58 ^{a} ± 10.12	30.0 ^{b} ± 0.86	6.6 ^{a} ± 0.41
WF	50.89 ^{d} ± 1.17	120 ^{d} ± 2.17	205.33 ^{b} ± 3.05	630.18 ^{c} ± 3.25	2.35 ^{c} ± 0.22	3.36 ^{c} ± 0.21
SF	65 ^{c} ± 0.52	136 ^{c} ± 3.25	186 ^{c} ± 1.65	560 ^{d} ± 2.70	1.75 ^{c} ± 0.11	1.03 ^{d} ± 0.10
LSD at 0.05	5.22403	9.65991	6.47022	5.93813	2.96878	0.29511
Pasta						
100% SF	65 ^{e} ± 0.18	136 ^{d} ± 1.15	186 ^{e} ± 0.65	560 ^{e} ± 2.16	1.75 ^{d} ± 0.10	1.03 ^{b} ± 0.03
100% QF	82 ^{d} ± 0.25	143 ^{cd} ± 1.49	680 ^{a} ± 0.72	1412.50 ^{a} ± 5.17	30.86 ^{c} ± 1.12	6.5 ^{a} ± 0.31
5% SAP + 95% QF	90 ^{c} ± 0.50	150 ^{bc} ± 1.35	650 ^{b} ± 1.16	1350 ^{b} ± 4.11	35.0 ^{bc} ± 1.18	6.0 ^{a} ± 0.15
10% SAP + 90% QF	105 ^{b} ± 1.05	156 ^{ab} ± 1.42	620 ^{c} ± 2.25	1300 ^{c} ± 3.55	40.0 ^{ab} ± 1.35	5.70 ^{a} ± 0.22
15% SAP + 85% QF	120 ^{a} ± 1.15	162 ^{a} ± 1.65	580 ^{d} ± 3.16	1260 ^{d} ± 2.82	45.0 ^{a} ± 1.42	5.40 ^{a} ± 0.17
LSD at 0.05	6.90756	10.92181	16.87293	17.10697	9.26782	1.33491
Pan bread						
100% WF	36.54 ^{e} ± 0.22	120 ^{d} ± 0.65	205 ^{d} ± 1.56	625 ^{e} ± 2.56	2.50 ^{e} ± 0.10	3.20 ^{c} ± 0.10
100% QF	82 ^{d} ± 0.53	126 ^{cd} ± 0.72	680 ^{a} ± 2.90	1410 ^{a} ± 3.70	30.86 ^{d} ± 0.16	4.96 ^{b} ± 0.19
5% SAP + 95% QF	91 ^{c} ± 0.65	132 ^{bc} ± 0.81	665 ^{a} ± 3.20	1360 ^{b} ± 3.22	35.0 ^{c} ± 0.22	6.0 ^{a} ± 0.32
10% SAP + 90% QF	106 ^{b} ± 0.72	138 ^{ab} ± 0.65	640 ^{b} ± 3.50	1310 ^{c} ± 3.10	40.0 ^{b} ± 0.29	5.70 ^{ab} ± 0.41
15% SAP + 85% QF	118 ^{a} ± 0.78	142 ^{a} ± 0.56	610 ^{c} ± 3.65	1270 ^{d} ± 3.05	45.0 ^{a} ± 0.33	5.40 ^{ab} ± 0.36
LSD at 0.05	6.30576	8.46000	17.83525	20.91368	4.36947	1.29407

The values are the mean ± SD of three replicates. The values in the same column followed by different letters are significantly different ($p < 0.05$).

3.3. Rheological Parameters

3.3.1. Farinograph Parameters

The farinograph parameters of semolina flour (SF), wheat flour (WF), quinoa flour (QF) and QF supplemented with *spirulina* algae powder (SAP) at different levels (5, 10 and 15%) are presented in Table 3. The water absorption of flours was significantly different, being higher in the case of QF (65.5%) compared with WF (59.8%) and SF (57.5%). The increase in water absorption might be because of the boost in protein and crude fiber amounts in QF [46]. Comparable results were noted by Atef et al. [47]. When QF was supplemented with SAP at different levels (5, 10 and 15%), the water absorption increased from 67.5% to 71.5%. The arrival time, dough development time and stability were higher in SF compared with WF and QF. The addition of 5, 10 and 15% SAP to QF increased the arrival time, dough development time and stability, from 3.5 to 4.5, 4.0 to 5.0 and 4.0 to 7.5 min, respectively. The weakening and mixing tolerance index were higher in QF compared with WF and SF. The addition of SAP at different levels (5, 10 and 15%) to QF decreased the weakening and mixing tolerance index from 140 to 110 BU and 55 to 40 BU, respectively. The increased mixing tolerance and extension values may be due to interactions between fibrous materials and gluten [48]. Our findings are consistent with those of Barkallah et al. [49], Rababah et al. [50], Cardone et al. [51] and Hussein et al. [20].

Table 3. Rheological parameters SF, WF, QF and QF composite.

Parameter	Control			QF Containing SAP (%)		
	SF	WF	QF	5	10	15
Farinograph parameters						
Water absorption (%)	57.5	59.8	65.5	67.5	69.5	71.5
Arrival time (min)	6.5	1.5	3.0	3.5	4.0	4.5
Development time (min)	10.5	3.0	5.5	4.0	4.5	5.0
Stability (min)	11	8.0	3.5	4.0	6.0	7.5
Weakening (BU)	55	70	160	140	120	110
Mixing tolerance index (BU)	25	40	60	55	50	40
Extinsograph parameters						
Extensibility (E) (mm)	-	140	105	120	130	140
Elasticity (BU)	-	350	550	485	450	420
Ratio (R/E)	-	2.5	5.24	4.04	3.46	3.00
Energy (cm^2)	-	110	77	80	90	100
Viscoamylograph parameters						
Temp. of transition (°C)	64.7	61.8	67.5	69.5	71.5	73.0
Max. of viscosity (BU)	560	525	3010	2800	2600	2400
Temp. of max. viscosity	88.7	86.5	94.5	92.5	90.0	88.0
Breakdown viscosity (BU)	2913	608	3000	3700	2400	2200
Setback viscosity (BU)	592	196	3030	2970	2900	2710

3.3.2. Extensograph Parameters

The extensograph parameters of WF, QF and QF supplemented with SAP at different levels (5, 10 and 15%) are presented in Table 3. The extensibility, elasticity and energy of dough were 140, 350, 110 and 105, 550, 77 for WF and QF, respectively. In these results, it can be noticed that the addition of SAP to QF in increasing proportions from 5% to 15% decreased the elasticity proportionally, while the extensibility and energy of the dough increased. The reduced gluten as a result of QF replacement with SAP made the dough's binding structure less robust. This might result from the existence of fiber and protein components that weaken the dough's gluten complex. It is widely known that the quality and quantity of gluten affect the viscoelastic properties of wheat dough. Thus, the viscoelastic characteristics improved as the gluten content rose. This decrease could be attributed to the absence of gluten fractions in QF. The present findings are in agreement with those of El-Sherief [52], Paraskevopoulou et al. [53], Harra et al. [54] and Hussein et al. [20].

3.3.3. Viscoamylograph Measurements

Table 3 provides the pasting properties of semolina flour (SF), wheat flour (WF), quinoa flour (QF), and mixtures of QF with SAP at different levels (5%, 10%, and 15%). The viscoamylograph, which measures the viscosity changes in a flour–water suspension as temperature increases, was used to evaluate the rheological properties of the dough. The parameters analyzed include temperature of transition, maximum viscosity, temperature of maximum viscosity, breakdown viscosity, and setback viscosity, all of which are presented in Table 3.

The results indicate that QF exhibited the highest values for the temperature of transition, maximum viscosity, temperature of maximum viscosity, breakdown viscosity, and setback viscosity, in that order. SF and WF followed with lower values for these parameters. The addition of SAP to QF at different levels (5% to 15%) resulted in decreases in all the viscoamylograph parameters, except for the temperature of transition, in which an increase was observed. These findings align with those of previous studies conducted by Ahmed et al. [55] and Martínez-Villaluenga et al. [56].

3.4. Physical Properties

3.4.1. A. Color and Cooking Quality of Pasta

The color of pasta is an essential factor that influences consumer acceptance. It is influenced by the ingredients used and the processing methods employed. In this study, the addition of SAP to pasta resulted in an attractive green color, as indicated by color measurements (Table 4). The darkness (L*) of the pasta increased with the addition of SAP, which can be attributed to the green color of SAP, in contrast to the control pasta made with SF or QF alone (0% SAP), which had the lowest b* value. Cooking the pasta resulted in a decrease in darkness and an increase in brightness, which may be due to the diffusion of SAP pigments into the cooking water.

The cooking quality of the pasta was evaluated based on parameters such as weight increase, cooking loss, and volume increase (Table 4). All these parameters increased significantly with higher levels of SAP addition. The improvement in cooking quality can be attributed to the high protein and fiber content of SAP, which interacts with gluten in SF. Gluten contributes to weight gain in pasta and helps retain its components. The presence of SAP may disrupt the formation of the protein network, leading to increased starch hydration and weight gain. The cooking loss, which measures the leaching of soluble starch and non-starch polysaccharides into the water, was less than 12% in the present study, indicating good-quality pasta. These findings are consistent with previous reports by Özyurt et al. [41], Hussein et al. [23], and Fouad et al. [57].

3.4.2. Color, Baking Quality, and Staling of Pan Bread

Color is an important quality factor that affects consumer preference for bakery products [58]. The results of color measurements for pan bread supplemented with different levels of SAP are presented in Table 4. The crust of the supplemented bread samples showed lower L* and b* values, indicating a darker color, which increased with higher levels of SAP fortification. In contrast, the a* values of the crust exhibited a reversed trend compared with the L* and b* values. In comparison with the control bread, the supplemented bread samples' crumb had lower a* and b* values. Overall, the supplemented bread samples possessed a darker crust and crumb, which might be attributed to the high fiber and phenolic acid content of SAP which promote the formation of Maillard reaction products throughout baking [59–61].

The physical properties of the pan bread, including weight, volume, specific volume, and alkaline water retention capacity (AWRC), were also evaluated (Table 4). The volume of the bread decreased with increasing levels of SAP, and a significant reduction was recorded at the 15% substitute level compared with the other levels. Accordingly, the specific volume, which is an indicator of bread quality, was lower in SAP-containing bread in comparison with the control sample. This can be attributed to the high fiber and protein content of SAP and its greater water-holding capacity, which led to the deformation of the gluten network and faster loss of CO_2, resulting in a compact crumb structure. These findings are consistent with studies by Masoodi et al. [62], Kohajdová et al. [63], and Zhou et al. [64].

Alkaline water retention capacity (AWRC), which measures the ability of bread to retain moisture and freshness, was used to assess the staling of pan bread. Wheat bread exhibited higher freshness compared with quinoa bread or quinoa bread supplemented with SAP at different levels (5%, 10%, and 15%). This indicates that quinoa bread staled faster than wheat bread, likely due to a higher loss of moisture content in the former. These outcomes are in line with the observed moisture loss. Similar findings were observed by Hussein et al. [65] when adding 30% barley flour to wheat flour for production of balady bread. Pan bread produced from QF supplemented with SAP showed increased freshness as SAP was added in increasing proportions from 5% to 15%. The data in the same table show that the bread made with quinoa remained fresher than the wheat bread. Bread containing SAP had higher values of AWRC than QF bread.

Table 4. Physical properties of pasta and pan bread samples.

Parameter	Control		QF Containing SAP (%)				LSD at 0.05
	SF	WF	QF	5	10	15	
Color attributes of raw pasta							
Lightness (L*)	74.97 ^{b} ± 2.12	-	76.11 ^{a} ± 0.22	71.11 ^{c} ± 0.14	67.15 ^{d} ± 0.30	64.55 ^{e} ± 1.53	0.30659
Redness (a*)	3.10 ^{e} ± 0.03	-	3.75 ^{d} ± 0.05	4.12 ^{c} ± 0.12	4.60 ^{b} ± 0.124	5.05 ^{a} ± 0.07	0.21328
Yellowness (b*)	14.73 ^{e} ± 0.28	-	17.22 ^{d} ± 0.12	22.97 ^{c} ± 0.56	23.57 ^{b} ± 0.03	24.09 ^{a} ± 0.07	0.16052
Color attributes of cooked pasta							
Lightness (L*)	77.41 ^{a} ± 0.97	-	69.15 ^{b} ± 0.30	66.12 ^{c} ± 0.22	62.17 ^{d} ± 0.23	59.38 ^{e} ± 0.35	0.32838
Redness (a*)	2.23 ^{e} ± 0.11	-	2.90 ^{d} ± 0.09	3.65 ^{b} ± 0.07	4.02 ^{c} ± 0.02	4.31 ^{a} ± 0.02	0.21328
Yellowness (b*)	19.46 ^{c} ± 0.64	-	16.01 ^{d} ± 0.15	23.17 ^{b} ± 0.17	23.55 ^{a} ± 0.07	23.76 ^{a} ± 0.05	0.28841
Cooking quality of pasta							
Weight increase (%)	220 ^{d} ± 2.82	-	230 ^{cd} ± 1.65	235 ^{c} ± 0.31	255 ^{b} ± 0.65	275 ^{a} ± 0.80	12.86118
Volume increase (%)	165 ^{d} ± 4.42	-	170 ^{d} ± 2.10	180 ^{c} ± 0.50	195 ^{b} ± 1.50	210 ^{a} ± 1.25	9.18125
Cooking loss (%)	3.5 ^{c} ± 0.14	-	6.0 ^{a} ± 0.55	5.5 ^{a} ± 0.22	5.0 ^{b} ± 0.25	4.03 ^{c} ± 0.20	0.50587
Color attributes of pan bread crust							
Lightness (L*)	-	42.65 ^{a} ± 1.13	36.22 ^{b} ± 1.53	34.05 ^{c} ± 1.7	33.25 ^{d} ± 1.62	31.17 ^{e} ± 1.1	0.12162
Redness (a*)	-	10.57 ^{e} ± 0.61	11.31 ^{d} ± 0.83	12.05 ^{c} ± 0.77	13.13 ^{b} ± 0.69	14.69 ^{a} ± 0.87	0.15902
Yellowness (b*)	-	25.23 ^{a} ± 1.76	18.34 ^{d} ± 1.66	19.82 ^{b} ± 1.95	18.75 ^{c} ± 1.87	17.88 ^{e} ± 1.69	0.25536
Color attributes of pan bread crumb							
Lightness (L*)	-	71.62 ^{a} ± 2.20	64.76 ^{b} ± 1.92	51.90 ^{c} ± 1.99	47.39 ^{d} ± 1.69	38.55 ^{e} ± 1.52	0.14653
Redness (a*)	-	3.45 ^{a} ± 0.08	1.09 ^{b} ± 0.05	0.94 ^{c} ± 0.03	0.91 ^{c} ± 0.02	1.02 ^{bc} ± 0.04	0.13287
Yellowness (b*)	-	22.23 ^{a} ± 1.00	15.41 ^{b} ± 0.97	15.58 ^{b} ± 0.96	14.38 ^{c} ± 0.90	14.05 ^{d} ± 0.82	0.19538
Baking quality of pan bread							
Weight (g)	-	70.1 ^{e} ± 1.2	72.2 ^{d} ± 1.5	75.1 ^{c} ± 1.9	77.1 ^{b} ± 1.2	79.0 ^{a} ± 1.8	0.95423
Volume (cm^3)	-	232 ^{a} ± 3.15	207 ^{b} ± 2.19	185 ^{c} ± 3.1	165 ^{d} ± 3.91	150 ^{e} ± 4.25	8.55348
Specific volume (cm^3/g)	-	3.3 ^{a} ± 0.11	2.88 ^{b} ± 0.10	2.47 ^{c} ± 0.08	2.14 ^{d} ± 0.09	1.90 ^{d} ± 0.77	0.27601
Freshness of pan bread							
Zero time	-	359.0 ^{a} ± 2.16	164.51 ^{e} ± 1.15	177.55 ^{d} ± 2.16	182.06 ^{c} ± 1.21	190.87 ^{b} ± 0.65	1.32390
1 days	-	322 ^{a} ± 3.15	158.99 ^{e} ± 1.05	165.16 ^{d} ± 1.66	172.31 ^{c} ± 0.68	177.82 ^{b} ± 0.50	2.53003
2 days	-	298 ^{a} ± 2.05	150.73 ^{e} ± 0.96	155.82 ^{d} ± 0.82	165.62 ^{c} ± 1.09	169.89 ^{b} ± 0.44	1.27107
3 days	-	265 ^{a} ± 1.78	144.32 ^{e} ± 0.68	147.34 ^{c} ± 0.78	153.89 ^{b} ± 1.22	158.31 ^{b} ± 0.39	6.30866

The values are the mean ± SD of three replicates. The values in the same column followed by different letters are significantly different ($p < 0.05$).

3.4.3. Sensory Properties

The results of the sensory evaluation tests demonstrated that the addition of quinoa *spirulina* (SP) to pasta at levels of 5% and 10% resulted in a significant reduction in all organoleptic parameters (color, flavor, mouthfeel, and overall acceptability) compared with the control samples made with 100% semolina flour (SF) or 100% quinoa flour (QF) without SP (Table 5). However, elasticity was the only parameter that did not show a significant change. The sensory characteristics of the pasta decreased as the level of SP addition increased. The reduction in color can be ascribed to the dark color (L*) of SP because of its pigments, as marked in the color measurements (Table 4). The results suggest that pasta can be enhanced with SP at levels of 5% or 10% without negatively affecting its sensory acceptance. These findings are consistent with the results obtained by Zen et al. [66].

In the case of pan bread, sensory evaluation plays a crucial role in determining consumer acceptability, considering parameters such as taste, aroma, crumb grain texture, crust color, crumb color, symmetry of shape, and overall approval. The sensory parameters of pan bread, including taste, aroma, crumb color, crust color, crumb texture, break and shred, mouthfeel, and symmetry of shape, were evaluated and are presented in Table 5. It was observed that all the formulations showed a significant decrease in all sensory parameters compared with the control sample made with 100% wheat flour (WF). However, pan bread produced by partially substituting quinoa flour (QF) with SAP at levels of 5%, 10%, and 15% exhibited good sensory properties. The decrease in sensory parameters of pan bread was attributed to the increased level of SAP in the formulation. The sensory scores for aroma, taste, crust color, crumb color, crumb grain texture, symmetry of shape, and mouthfeel of pan bread decreased as the level of SAP increased. These outcomes support the conclusions made by Bastidas et al. [67].

Table 5. Organoleptic characteristics of pasta and pan bread.

Parameter	Control			QF Containing SAP (%)			LSD at 0.05
	SF	WF	QF	5	10	15	
Organoleptic characteristics of pasta							
Color (10)	9.75 ^{a} ± 0.35	-	8.9 ^{c} ± 0.42	9.01 ^{b} ± 0.44	8.12 ^{c} ± 0.52	6.44 ^{d} ± 0.70	0.18748
Flavor (10)	9.83 ^{a} ± 0.28	-	9.33 ^{b} ± 0.57	9.33 ^{b} ± 0.45	8.44 ^{c} ± 0.37	7.35 ^{d} ± 0.41	0.2584
Mouthfeel (10)	9.70 ± 0.23 ^{a}	-	9.01 ± 0.42a	9.41 ^{a} ± 0.52	8.80 ^{a} ± 0.55	6.82 ^{c} ± 0.56	0.22944
Elasticity (10)	9.81 ^{a} ± 0.25	-	8.50 ^{b} ± 0.35	9.50 ^{b} ± 0.41	9.21 ^{c} ± 0.37	9.01 ^{d} ± 0.61	0.26394
Overall-acceptability (10)	9.55 ^{a} ± 0.52	-	8.95 ^{c} ± 0.46	9.11 ^{b} ± 0.35	8.80 ^{d} ± 0.42	7.35 ^{e} ± 0.33	0.13045
Total score (50)	47.81 ^{a} ± 1.02	-	44.18 ^{c} ± 1.25 ^{b}	46.36 ^{b} ± 1.28	43.37 ^{d} ± 1.51	36.97 ^{e} ± 1.12	0.07671
Organoleptic characteristics of pan bread							
Taste (20)	-	18.70 ^{a} ± 0.15	17.30 ^{b} ± 0.10	16.78 ^{c} ± 0.10	16.55 ^{c} ± 0.17	14.65 ^{d} ± 0.09	0.29684
Aroma (20)	-	19.22 ^{a} ± 0.11	17.53 ^{b} ± 0.12	16.11 ^{c} ± 0.12	15.25 ^{d} ± 0.15	13.75 ^{e} ± 0.07	0.14043
Crumb color (10)	-	9.20 ^{a} ± 0.13	7.14 ^{b} ± 0.17	7.11 ^{b} ± 0.15	7.05 ^{b} ± 0.13	5.31 ^{c} ± 0.01	0.12485
Crust color (10)	-	8.95 ^{a} ± 0.10	6.97 ^{b} ± 0.11	6.50 ^{b} ± 0.09	6.35 ^{c} ± 0.09	5.30 ^{d} ± 0.011	0.16101
Crumb texture (15)	-	14.36 ^{a} ± 0.17	13.12 ^{c} ± 0.09	13.04 ^{c} ± 0.17	13.55 ^{b} ± 0.06	11.66 ^{d} ± 0.12	0.11420
Break and shred (10)	-	9.50 ^{a} ± 0.09	8.24 ^{b} ± 0.12	7.45 ^{c} ± 0.10	7.30 ^{c} ± 0.04	7.11 ^{d} ± 0.09	0.17924
Mouth feel (10)	-	9.12 ^{a} ± 0.07	8.62 ^{b} ± 0.13	8.00 ^{c} ± 0.08	7.52 ^{d} ± 0.07	5.95 ^{e} ± 0.06	0.18145
Symmetry shape (5)	-	4.6 ^{a} ± 0.05	4.01 ^{b} ± 0.09	3.56 ^{c} ± 0.07	3.15 ^{d} ± 0.05	2.94 ^{d} ± 0.03	0.26634

The values are the mean ± SD of three replicates. The values in the same column followed by different letters are significantly different ($p < 0.05$).

3.4.4. Texture Profile

Table 6 presents the texture parameters of pasta and bread samples made from different formulations, including semolina flour (SF), quinoa flour (QF), and QF supplemented with *spirulina* (SAP) at various levels (5%, 10%, and 15%). The texture parameters analyzed include hardness (N), deformation at hardness (mm), deformation at hardness (%), hardness work (mJ), load at target (N), peak stress (N/m^2), strain at peak load, fracturability (N), and fracturability with 1% of load sensitivity (N).

For pasta, the results showed that the hardness (N) ranged from 73.10 to 47.55 N for all samples. Pasta without SAP had higher hardness, which can be attributed to lower moisture content. The hardness of pasta is an important sensory attribute for consumers and is influenced by the product's cell structure and expansion, regardless of moisture content. These findings are consistent with previous studies by De Marco et al. [68], Raja et al. [69], and Jaworska et al. [70]. The addition of SAP at different levels (5%, 10%, and 15%) decreased the hardness (N), deformation at hardness (mm), deformation at hardness (%), hardness work (mJ), and fracturability with 1% of load sensitivity (N) of the pasta. However, the hardness increased when QF was supplemented with SAP.

In the case of bread, the addition of SAP to QF affected the texture attributes of the bread. Compared with bread prepared from wheat flour (WF), the rigidity of bread samples grew by 72% with increasing levels of SAP supplementation. Bread rigidity (hardness) is an essential property that impacts consumers' perception of bread freshness, and it is influenced by the interaction between gluten and fiber materials. Elasticity, which measures how much bread crumbs rebound after being compressed, was slightly lower in bread samples made from QF and QF supplemented with SAP compared with the control sample. The springiness and cohesiveness values of the bread samples were also affected by SAP supplementation, with decreased values observed. Chewiness, which represents the work required to chew solid samples, including bread, followed a similar trend to hardness. Overall, all treatments had more elevated chewiness than the control samples, with bread samples supplemented with 10% SAP showing the highest chewiness value. The data presented here agree with those provided by El-Sohaimy et al. [15].

Table 6. Texture profile analysis of pasta and pan bread.

Parameter	Control			QF Containing SAP (%)		
	SF	WF	QF	5	10	15
Texture profile analysis of raw pasta						
Hardness (N)	73.10	-	53.13	53.90	53.70	47.55
Deformation at hardness (mm)	0.26	-	0.23	6.22	5.54	8.30
% Deformation at hardness (%)	0.90	-	0.80	20.70	18.50	27.70
Hardness work (mJ)	0.40	-	13.20	39.10	50.90	63.70
Load at target (N)	72.07	-	53.13	41.48	53.70	44.55
Peak stress (N/m^2)	36,704	-	27,060	21,127	27,350	22,690
Strain at peak load	0.01	-	0.01	0.21	0.18	0.28
Fracturability (N)	72.07	-	53.13	29.92	32.91	36.03
Fracture load drop off (N)	64.02	-	45.83	28.53	28.93	27.30
1st fracture work done (mJ)	11.90	-	7.40	3.30	5.00	7.90
1st fracture deformation (mm)	0.26	-	0.23	0.17	0.23	0.32
1st fracture % deformation (%)	0.90	-	0.80	0.60	0.80	1.10

Table 6. *Cont.*

Parameter	Control			QF Containing SAP (%)		
	SF	WF	QF	5	10	15
Texture profile analysis of cooked pasta						
Hardness (N)	7.02	-	7.05	6.93	5.49	6.88
Deformation at hardness (mm)	8.56	-	8.79	10.78	10.57	11.12
% Deformation at hardness (%)	85.60	-	87.90	107.80	105.70	111.20
Hardness work (mJ)	22.50	-	22.90	33.80	25.20	39.60
Load at target (N)	7.02	-	7.05	6.93	5.49	6.88
Peak stress (N/m^2)	3576	-	3591	3531	2797	3506
Strain at peak load	0.86	-	0.88	1.08	1.06	1.11
Fracturability (N)	0.37	-	0.31	0.21	0.42	0.58
Fracture load drop Off (N)	0.15	-	0.08	0.17	0.12	0.13
1st fracture work done (mJ)	0.02	-	0.03	0.02	0.10	0.13
1st fracture deformation (mm)	0.20	-	0.30	0.20	1.00	1.30
1st fracture % deformation (%)	7.02	-	7.05	12.93	12.01	11.54
Texture profile analysis of pan bread						
Hardness (N)	-	586	516	525	535	550
Hardness work cycle 1 (mJ)	-	21.80	20.80	21.10	21.50	21.90
Recoverable work cycle 1 (mJ)	-	11.80	11.9	12.0	12.10	12.20
Hardness work cycle 2 (mJ)	-	20.70	20.50	20.60	20.80	20.90
Recoverable work cycle 2 (mJ)	-	9.10	11.0	11.40	11.75	12.05
Cohesiveness	-	0.95	0.98	0.97	0.99	1.01
Adhesiveness (mJ)	-	0.30	0.10	0.15	0.19	0.25
Springiness (mm)	-	19.70	17.64	17.75	17.85	17.95
Springiness index	-	0.95	0.96	1.0	1.15	1.30
Gumminess (g)	-	556.4	508.6	520	535	550
Chewiness (gmm)	-	4240	3885	4020	4125	4280
Resilience	-	0.54	0.57	0.59	0.63	0.69

3.4.5. Anthropometric

The results revealed that consumption of pasta and pan bread rich in protein (as demonstrated from the chemical composition of the supplements) provided a beneficial effect in preserving lean body mass by increasing body muscle mass numerically but without statistical significance. Furthermore, there were statistically significant differences in the increase in the basal metabolic rate, which resulted in decreases in the percentage body fat (Table 7). The human body works as a machine which breaks down the food consumed to be transformed to nutrients that are easily absorbed and produce energy essential for different cellular functions and metabolism. Our results agree with those of Kim et al. [71], who demonstrated that protein consumption increase fat burning thermogenesis. Moon and Koh [72] determined that a high protein diet resulted in weight loss and decreased the incidence of cardiovascular diseases risk factors, such as serum triglyceride level, and controlled blood pressure whilst retaining free fat mass. This result was observed in both an energy-restricted diet and in standard energy diets with follow-up intervals for one year. The resting energy rate consumes 70 per cent of calories per day, depending on body composition, age, sex, physical activity and medical status [73]. The foods tested here can be easily prepared at home as all the ingredients used are available in Egyptian and worldwide cuisines.

Table 7. Mean ± SD of anthropometric parameters.

Parameters	Group (Pasta: 15% SAP + 85% QF) (n = 27)		Group (Pan Bread: 15% SAP + 85% QF) (n = 28)	
	Base	Last Day	Base	Last Day
Age (year)	36.33 ± 1.70		31.72 ± 0.93	
Sex	Females		Females	
BMI (kg/m^2)	33.0 ± 4.13	32.1 ± 4.08	35.71 ± 3.70	34.99 ± 2.61
% BF	31.72 ± 2.98	28.07 ± 2.99 *[a]	32.54 ± 3.67	30.39 ± 2.67 *[b]
LBM	44.70 ± 3.95	46.46 ± 3.54	42.88 ± 0.53	43.18 ± 0.61
BMR	2082.26 ± 215.89	2152.84 ± 261.85 *[a]	1979.53 ± 312.97	2127.00 ± 307.15 *[b]

SAP = *spirulina* algae powder; QF = quinoa flour; BMI = body mass index; % BF = % body fat; LBM = lean body mass; BMR = basal metabolic rate. [a]: basal vs. last in pasta group, and [b]: basal vs. last in pancake group, * $p < 0.05$.

4. Conclusions

Our findings indicate that *spirulina* algae powder could be combined with quinoa flour to create gluten-free pasta and pan bread with good sensory properties, higher nutritional value and enhanced rheological properties. The products also had positive impacts on basal metabolic rate and lean body mass. Overall, the results suggest that pasta and pan bread can be enriched with SP at levels of 5% or 10% without negatively affecting their sensory acceptance. These products could be particularly suitable for athletes and for patients with celiac disease or obesity.

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