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Title: Quality indicators and heat damage of dried and cooked gluten free spaghetti

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Abstract

The quality and safety indicators of commercial dried gluten free (GF) pasta were analyzed to investigate, for the first time, the real nutritional intake through the chemical composition and the heat damage during processing by quantification of furosine. Eight samples of GF spaghetti were compared with wheat spaghetti. Dried and cooked GF pasta had lower protein and ash content than wheat spaghetti. GF samples composed solely by corn flour had higher optimal cooking time. Samples with emulsifier showed lower losses during cooking. Considering their composition, no trend could be established to explain textural behavior. Samples constituted merely by corn showed the highest resilience and elasticity. Spaghetti constituted only from corn and rice showed the highest firmness. The furosine content in dried samples ranged between 19 – 134 mg FUR/100 g proteins and in cooked samples ranged between 48 to 360 mg FUR/100 g proteins. Furosine content of GF pasta was in general lower than in wheat pasta, and those differences were even enlarged when comparing them after cooking. The results of PCA indicated it was possible to discriminate GF pasta regarding their technological and nutritional behavior.

Keywords: gluten free pasta; cooking quality; heat damage; furosine.

Introduction

Consumption of gluten free (GF) products has become trendy because of growing number of diagnosed celiac patients and the adoption of gluten free diets not related to pathologies. Among the non-gluten foods, pasta is one of the most consumed due to its convenience, palatability and long shelf-life [1]. Although gluten pasta could be considered a simple processed food, it gets more complex when going to GF pasta. A good quality pasta is characterized by adequate performance during cooking, which depends on the raw materials, particularly the quantity and quality of proteins and starch that give rise to the formation of a gluten network that traps the starch granules [2]. In the case of GF pasta, to develop a pseudo gluten network, the industry uses different ingredients (flour/starch from corn, rice, tapioca, pseudo cereals and legumes) and may add emulsifiers, hydrocolloids or adopt nonconventional pasta-making processes [1]. Consequently, market offers a great range of GF pasta, which in opposition to what happens with gluten pasta, shows great variability. Nevertheless, the integration of the different ingredients might lead to complete different pseudo gluten network with rather diverse performance during cooking, and in turn, pasta quality characteristics. Similarly, scarce attention has been paid to their nutritional quality. Previous studies have pointed out the deficient nutritional pattern of GF breads [3,4], but information regarding the GF pasta is almost non-existent.

The diverse composition of GF pasta might respond different to process, particularly to pasta drying, which is a decisive stage for ensuring its microbiological stability by keeping final water content lower than 12.5 %. The High Temperature-Short Time system (> 75 to 100 °C for 2 to 3 h) usually applied for pasta drying allows producing gluten pasta with excellent cooking properties [5], but with a concomitant increasing risk of occurring Maillard reaction (MR) and the release of melanoidins as final products [6]. In early stages of MR, Amadori compounds (fructosyl-lysine, lactulosyl-lysine, and maltulosyl-lysine) are formed, which generate

furosine (FUR) (ϵ -N-furoylmethyl-L-lysine) that has been established as a good marker of heat damage during pasta processing, as well as an indicator for the nutritional value and safety of the pasta products. Moreover, in the last years, some studies have stressed the toxic consequences of FUR on the biological system, specifically its adverse effects on mice liver and kidney [7].

The aim of this study was to analyze the quality indicators of commercial gluten free pasta (cooking behavior, color, texture properties), to investigate for the first time the real nutritional intake through the chemical composition of commercial cooked GF pasta and to evaluate the heat damage by quantification of FUR in dried and cooked GF pasta.

Materials and Methods

A total of 8 commercial GF spaghetti samples, manufactured by different European companies, were purchased in the market. Samples were labeled with different codes for identification, GF1, GF2, GF3, GF4, GF5, GF6, GF7, GF8, respectively. A wheat pasta was also included as a reference and labeled as W. Information contained in the package was recorded (Table 1). Chemical reagents and solvents of analytical grade were purchased to Sigma–Aldrich (Madrid, Spain). Standard of furosine was from Extrasynthese (Genay, France). Hydrochloric acid (37%) and methanol were purchased from Merck (Darmstadt, Germany). Ultra-pure water was obtained using a Mili-Q water purification system (Millipore, U.S.A.).

Cooking quality indicators

Optimal cooking time (OCT) was evaluated according to AACC official method [8] with some modifications. Spaghetti (5 g) were cooked in 60 mL of boiling water and every 30 s spaghettis were squeezed between two Petri dishes to determine the OCT that corresponded to the disappearance of the white core (ungelatinized starch). For each sample, two measurements were performed.

Cooking loss (CL), the organic material lost during cooking, was analyzed. For that, the cooking water was dried to constant weight in an air oven at 65 °C. The remnant (solid loss) was weighted and expressed as percentage following equation 1. The mean value was a result of three replicates.

$$CL (\%) = \frac{\text{Solid loss (g)}}{\text{Raw Pasta (g)}} \times 100 \text{ [Equation 1]}$$

Water absorption (WA) was determined weighting five pieces of cooked spaghetti (5 cm long) and following the equation 2 as reported by Tudorică et al. [9]:

$$WA (\%) = \frac{\text{Cooked (g)} - \text{Raw Pasta (g)}}{\text{Raw Pasta (g)}} \times 100 \text{ [Equation 2]}$$

Three measurements were performed for each analysis, and the mean values were calculated.

Swelling index (SI) was determined following the same steps of WA, five pieces of cooked spaghettis (5 cm long) were weighted and dried during 24 h to constant weight in air oven at 65°C. SI was determined following the equation 3:

$$SI (\text{g water/g dry pasta}) = \frac{\text{Cooked Pasta (g)} - \text{Cooked Pasta after drying (g)}}{\text{Cooked Pasta after drying (g)}} \text{ [Equation 3]}$$

Each sample was analyzed in triplicate and mean value was noted.

Color of dried and cooked spaghetti was measured by a Minolta Chromameter (Model CR-400, Minolta Co., Osaka, Japan) using CIELAB coordinates. L^* for the lightness (0 - 100), a^* for the green – red (negative values relate to green while the positive ones refer to red) and b^* for blue – yellow b^* (negative values relate to blue while the positive ones refer to yellow). From these parameters, the cylindrical coordinates hue or hue angle (h_{ab}) and Chroma (C^*_{ab}) were obtained following the equations 4 and 5 and the mean value came from five measurements.

$$C^*_{ab} = \sqrt{(a^*)^2 + (b^*)^2} \text{ [Equation 4]}$$

$$h_{ab} = \tan^{-1} \left(\frac{b^*}{a^*} \right) \text{ [Equation 5]}$$

Pasta characterization

Dried and cooked spaghetti samples were analyzed for moisture content, crude protein by Dumas Combustion Principle using 6.25 as conversion factor, total fat and ash following the ICC standard methods [10]. Total carbohydrates data were obtained by subtraction from 100 the moisture, protein, fat and ash values. Results are the average of two determinations and are expressed as g/100 g.

Using the Texture Analyzer (TAHDi/500, TAHD Co., Stable Micro System, Surrey, UK) the texture profile analysis (TPA) was studied. The instrument was equipped with a load cell of 30 Kg and P/36 cylinder probe (36 mm Ø) and the following settings were used: pre-test speed, test speed and post-test speed was 2 mm/s, and trigger force was 10 g. The distance was 10 mm with 75% strain and holding time between compressions was 2 s. Five pieces (5 cm long) of cooked spaghetti were submitted to a double compression and Hardness, Adhesiveness, Chewiness and Resilience were measured using five replicates; data were calculated using the software of the instrument. Following the official method of the AACC International [8], firmness (g) (the maximum force necessary to cut spaghetti) and work of shear (g·s) (the area under the curve of force/time graphic) were investigated using a Texture Analyzer (TAHDi/500, TAHD Co., Stable Micro System, Surrey, UK) fitted with a plastic cutting tool. Each sample was analyzed in triple and data were calculated by software instrument. Elastic limit (g) and elasticity (mm) of spaghetti were determined by a Texture Analyzer equipped with a load cell of 30 Kg and with tensile grips (ref. A/SPR, Stable Micro Systems), following certain conditions: test speed was 3 mm/s and initial distance was 100 mm. Five measurements were performed for each sample and data calculated by the instrument software.

Furosine determination

Furosine was determined in dried and cooked spaghettis. Previously to furosine determination, cooked samples were lyophilized for 24 h at -70 °C and 933.26 Pa with a Virtis SP Scientific equipment (Pennsylvania, United States). Samples were hydrolyzed with 8 N HCl at 110°C for

24 h. One milliliter of the hydrolysate was filtered in a 0.22 μ m cellulose filter. Chromatographic determination of FUR in pasta samples was performed on a HPLC instrument (HP Series 1050, USA) with a DAD detector (1040A) following the method of Li et al. [11]. The separation of FUR was accomplished on a C18 column (4.6 x 150 mm, 5 μ m, Hewlett-Packard) and two mobile phases consisting of 0.1% trifluoroacetic acid (TFA) in water (A) and 0.1% TFA in acetonitrile (B). A gradient elution, 1-21% B at 0-25 min and 21-1% B at 25-30 min, was applied. A cleaning process with 1% tetrahydrofuran (THF) during 5 min was performed after each sample analysis. The flow rate was maintained at 1 mL/min. The identification of FUR was carried out by DAD spectra and the quantification was performed by an external standard method. The content of FUR was expressed as mg of compound in 100 mg of proteins. The analyses of each sample were carried out in duplicates.

Statistical analysis

Data were analyzed by One-Way analysis of variance (ANOVA) and multiple sample comparison, which was performed by using Statgraphics Centurion XVII (Statpoint Technologies, Warrenton, USA). Fisher's least significant differences (LSD) test was used to describe means with 95% confidence. Principal Component Analysis (PCA) was also performed to significantly differentiate ($P < 0.05$) among samples.

Results and Discussion

Chemical composition

Most of the commercial samples of GF spaghetti analyzed in this study contained a mixture of corn and rice flours in their formulations; only two GF samples were composed only by corn, as shown in Table 1. Quinoa flour was present in two of the samples and other ingredients included brown rice and millet flour. Despite their coincidence in ingredients, there was significant difference in their nutritional composition (Table 2). Dried and cooked GF pasta had lower protein and ash content than wheat pasta, except for GF2, likely due to the presence of

144 millet in the formulation as it has higher mineral content than corn or rice [12]. Conversely,
145 dried GF pasta contained higher amount of fats than wheat pasta, excepting GF3, but those
146 differences were greatly reduced in the cooked pasta. Differences among dried and cooked
147 pasta confirms that cooking promoted significant losses of nutrients. When proximate
148 composition (Table 2) of dried and cooked pasta was compared, it was observed that ash and
149 carbohydrates were released to the cooking water, resulting in higher protein content in the
150 cooked pasta. Cooking affected the fat content of the GF pasta in different way, increasing it in
151 GF7 but decreasing in GF1, GF5 and GF6.

152 Different cooking indicators (OCT, CL, WA, SI) of the cooking quality were evaluated (Table
153 3). GF samples had higher OCT than the wheat control, indicating that GF pasta required
154 longer cooking to gelatinize all the starch granules, particularly those composed solely by corn
155 flour (GF4 and GF5). Significant variability was observed among the amount of solid losses
156 during cooking (CL). Considering that lower values are associated to better consistency and
157 low stickiness [13], which in wheat pasta are related to the development of a stable and strong
158 network of coagulated gluten proteins that entraps the starch granules [14], GF matrixes gave
159 diverse network. In general, samples with emulsifier (GF1, GF3, GF6, GF8) showed lower CL,
160 and samples only composed by corn (GF4 and GF5) had higher CL. Indeed, emulsifiers can
161 interact with starch and/or protein [15] to form a good structure reducing the cooking losses. As
162 described by Schoenlechner et al. [15], the use of emulsifiers (1.2 %) reduced cooking loss of
163 gluten-free pasta made with quinoa, amaranth and buckwheat flour blends. Great variability
164 was also observed in the water absorption (WA) that ranged from 49 % (GF2) to 107 % (GF7).
165 In fact, there was a strong negative correlation between WA and CL ($r = -0.73$, $P < 0.001$).
166 Regarding SI, or rather the capacity of protein-starch-fiber network to retain the water, the
167 highest value was obtained with GF5 that only contains corn flour. Results agree with those
168 reported by Foschia et al. [16]. Results related to the pasta color (Table 2) show that in the

dried group, GF4 and GF7 had the highest values of Hue Angle and with GF5 they had the highest Chroma values. Among the cooked samples GF1, GF7 and GF8 were found to be the samples with Hue Angle highest values. Nevertheless, cooking affected the Chroma parameter, in fact all the cooked samples had lower values than the ones observed for the dried group. GF4 and GF5 had the highest Chroma parameter, related to yellowness, which could be expected owing to the solely presence of corn flour in their composition.

Texture properties

Texture properties of cooked pasta were evaluated (Table 3). Hardness, a required force to get a compression of spaghetti strands, is a good index of the pasta consistency. GF7 showed the highest consistency followed by GF6 and GF8. Hardness values were within the range obtained by Motta Romero et al. [17], when making pasta with proso millet flour and hydrocolloids (4480 – 8454 g). A negative weak correlation ($r = -0.5125$; $P < 0.05$) was found between hardness and the protein content in cooked sample, thus when the proteins amount increased, hardness decreased. Adhesiveness, related to the stickiness of pasta, also significantly varied within samples, showing GF8 the lowest value and GF4 was the stickiest owing to its highest adhesiveness. No trend could be established to explain that behavior considering the composition. In general, chewiness of GF pasta was higher than that of wheat pasta, thus high energy was required for swallowing GF spaghetti. Resilience of GF pasta was higher than that of wheat pasta, except for GF7 and GF8. GF4 and GF5, made with corn flour, showed the highest resilience or capacity to recuperate the initial state after compression force. GF5 also showed the highest firmness, which is related to good quality pasta. Firmness values were close to those reported for wheat-based spaghetti (174-183 g) [18] and much lower than those reported by Bouasla et al. [19] when gluten free pasta was enriched with different amount and kind of legumes flours (199.50 - 326.50 N). The work of shear showed the same tendency of firmness. Elastic limit, measured as the resistance (g) to extension was higher in GF1, GF4,

GF5 and GF8 had the lowest value. A strong positive correlation ($r = 0.8366$; $P < 0.05$) was observed between elastic limit and resilience, namely samples with high capacity to recuperate the state before compression had more resistance to tensile force. Elasticity (mm) was higher in pasta made simply by corn flour (GF4 and GF5).

Furosine content

Furosine were measured to assess possible heat damage during pasta drying. The statistical analysis showed significant differences ($P < 0.05$) in FUR content in both pasta samples: dried and cooked (Table 2), indicating high variability in drying conditions and raw materials in all 9 pasta samples. No information has been previously reported regarding the content of FUR in GF pasta. Values of FUR in dried pasta ranged between 19 – 134 mg FUR/100 g proteins, with the highest values of FUR obtained for samples GF3 and GF5 (134 and 95 mg FUR/100 g proteins, respectively). Much research has been dedicated to demonstrate the influence of drying cycles on FUR content in wheat pasta, ranging from 45 up to 209 mg/100 g of protein for pasta from artisanal processes (short temperatures long times), while in industrial ones (high temperatures short times) FUR reached values from 390 up to 562 mg/100 g of proteins [5, 20]. In addition, recipes can also impact the FUR content of wheat spaghetti. In fact, in those enriched with common bean, values of FUR ranged between 25 – 77 mg /100 g of proteins with higher values obtained in products with higher bean content (30 %) and higher drying temperatures (80 °C) [17]. In lupine enriched spaghetti (0-20 %) FUR values ranged between 200 – 300 mg /100 g of protein after drying at 60 °C for 18-20 h [21]. Cooking process significantly increased the FUR content ($P < 0.05$) except in GF5, in which unexpectedly the FUR content significantly decreased. However, some authors have pointed out that Amadori compounds, which are formed in the early stages of the MR, are not stable and they are easily converted to intermediate and final products, depending on the progress of the MR [22]. In fact, GF5 had the highest cooking time. According to Giannetti et al. [20] high intensity heat

treatments can promote a dramatic progression of MR leading to FUR underestimation. The values obtained in cooked samples ranged between 48 - 360 mg FUR/100 g proteins with an increase in the content of FUR of around 38%. The highest FUR content was obtained for wheat pasta. Despite the toxicity of FUR, no data on the content of FUR in pasta after cooking are available in the literature. Only FUR content of fresh wheat egg pasta after double pasteurization (1: 95 °C for 1.5 min; 2: 70 – 93 °C for 60 - 90 min) were reported in the range 11.12 – 87.61 mg/ 100 g of proteins [23].

Principal Component Analysis

To understand the possible role of specific GF ingredients in the quality of the resulting pasta, all the parameters were subjected to a principal component analysis. The results of PCA indicated that 34% and 23% of the variation was explained by principal components 1 (PC1) and 2 (PC2), respectively (Figure 1). GF2 and GF3 were the samples closer to wheat durum pasta for protein and ash content, furosine and work of shear. GF1, GF4 and GF5, behaved similar regarding cooking performance (OCT, CL, SI), texture (adhesiveness, resilience, firmness, elastic limit, elasticity) and color (Hue angle of dried samples and Chroma in cooked stage). GF6, GF7 and GF8 had in common water absorption. Therefore, it was possible to discriminate GF pasta regarding their technological and nutritional behavior.

Conclusion

There were significant differences in the nutritional composition between the gluten free spaghetti and the durum wheat pasta. In general, gluten free samples in both stage (dried and cooked) were poorer in protein and ash with respect to the wheat pasta. Regarding quality indicators, GF samples showed significantly different behavior, and they could not be related to specific ingredients. Nevertheless, pasta made with corn flour required longer cooking and had high cooking loss values but resulted in more resilient and elastic pasta. The furosine content in dried GF pasta was majorly lower than that in wheat pasta, and those differences were greatly

magnified after cooking. In the recent years, food technology applied to gluten free pasta production has taken great steps forward. Nevertheless, looking at the results, today nutritional improvements and new technologies approaches are needed to assure a nutritional balanced food.

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Figure captions

Figure 1. Score plot from a principal component analysis of the combination of components weight (chemical composition▲, cooking quality indicators ○, texture parameters• and furosine content●)

Figure 1.

Code	Ingredients
GF1	White Corn Flour, Yellow Corn Flour, Rice Flour, Water, Emulsifier: E-471 Mono and Diglycerides of fatty acids
GF2	Corn Flour, Millet Flour, Rice Flour, Cane sugar syrup
GF3	Corn Flour, Rice Flour, Corn Starch, Quinoa Flour, Emulsifier: E-471 Mono and

	Diglycerides of fatty acids
GF4	Corn Flour
GF5	Corn Flour
GF6	Corn Flour, Rice Flour, Brown Rice Flour, Quinoa Flour, Emulsifier: E-471 Mono and Diglycerides of fatty acids
GF7	Corn Flour, Rice Flour
GF8	Corn Flour, Rice Flour, Emulsifier: E-471 Mono and Diglycerides of fatty acids
W	Durum Wheat Semolina

327 Table 1. Ingredients in commercial gluten free pasta as indicated in the label.

328 Table 2. Proximate composition (d.b.), furosine content (d.b.) and color of the pasta samples before and after cooking.

Sample	Dried																												
	Moisture (%)			Ash (%)			Protein (%)			Fat (%)		Carbohydrates (%)		Furosine (mg/100 g of protein)		Hue angle		Chroma											
GF1	10.02	±	0.13	b	0.31	±	0.01	a	8.37	±	0.04	e	1.17	±	0.19	cd	80.14	24	±	2	ab	-1.52	±	0.00	c	57.25	±	4.92	cd
GF2	9.89	±	0.18	b	0.89	±	0.00	f	9.90	±	0.02	g	1.08	±	0.22	c	78.23	19	±	1	a	1.53	±	0.00	e	55.61	±	0.79	bc
GF3	11.52	±	0.08	de	0.42	±	0.00	c	7.71	±	0.02	d	0.68	±	0.00	a	79.67	134	±	2	g	-1.56	±	0.00	a	51.85	±	0.43	a
GF4	11.26	±	0.17	cde	0.37	±	0.00	b	5.42	±	0.03	b	1.42	±	0.12	d	81.52	66	±	3	d	1.57	±	0.00	f	64.81	±	1.52	g
GF5	11.88	±	0.53	e	0.43	±	0.00	c	5.29	±	0.01	a	1.05	±	0.02	bc	81.35	95	±	6	e	1.51	±	0.00	d	62.66	±	2.28	fg
GF6	11.22	±	0.81	cde	0.49	±	0.00	d	8.86	±	0.07	f	1.19	±	0.01	cd	78.24	49	±	5	c	-1.55	±	0.00	b	60.44	±	1.46	ef
GF7	10.48	±	0.16	bc	0.63	±	0.02	e	7.12	±	0.19	c	0.95	±	0.15	abc	80.82	30	±	2	b	1.57	±	0.00	f	64.80	±	1.54	g
GF8	10.85	±	0.14	cd	0.64	±	0.01	e	7.00	±	0.07	c	0.95	±	0.04	abc	80.56	50	±	2	c	-1.53	±	0.00	c	59.85	±	0.74	de
W	8.78	±	0.20	a	0.90	±	0.01	f	13.78	±	0.03	h	0.76	±	0.19	ab	75.78	121	±	1	f	1.53	±	0.01	e	53.62	±	1.51	ab
	Cooked																												
GF1	65.62	±	0.18	b	0.18	±	0.03	a	8.92	±	0.01	e	0.87	±	0.02	ab	24.41	84	±	0	bc	-1.43	±	0.01	d	34.48	±	3.60	c
GF2	66.32	±	0.07	bc	0.61	±	0.05	d	10.81	±	0.06	g	1.12	±	0.21	bcd	21.14	71	±	7	b	-1.49	±	0.00	b	30.32	±	0.80	b
GF3	64.57	±	0.18	a	0.31	±	0.01	bc	8.24	±	0.04	d	0.85	±	0.19	ab	26.03	198	±	7	e	-1.47	±	0.02	bc	16.53	±	2.18	a
GF4	66.81	±	0.04	cd	0.17	±	0.05	a	5.97	±	0.01	b	1.17	±	0.09	cd	25.88	131	±	6	d	-1.48	±	0.00	b	42.49	±	1.21	d
GF5	69.78	±	0.13	f	0.24	±	0.10	ab	5.63	±	0.03	a	0.82	±	0.05	a	23.53	48	±	1	a	-1.49	±	0.01	b	40.52	±	3.05	d
GF6	67.32	±	0.78	d	0.31	±	0.01	bc	9.32	±	0.10	f	0.70	±	0.03	a	22.36	79	±	5	bc	-1.45	±	0.03	cd	17.34	±	2.36	a
GF7	67.38	±	1.08	d	0.38	±	0.02	c	7.44	±	0.05	c	1.32	±	0.12	d	23.48	77	±	6	b	-1.43	±	0.05	d	16.53	±	1.28	a
GF8	68.17	±	0.03	e	0.39	±	0.01	c	7.56	±	0.10	c	0.90	±	0.14	ab	22.99	91	±	10	c	-1.43	±	0.03	d	29.85	±	2.95	b
W	67.15	±	0.06	d	0.60	±	0.02	d	14.46	±	0.01	h	0.92	±	0.04	abc	16.87	360	±	4	f	-1.52	±	0.00	a	29.77	±	0.48	b

329 Mean ± standard deviation. Different letters within the same parameter for dried or cooked pasta differ significantly ($P < 0.05$)

Sample	OCT (min)	CL (%)	WA (%)	SI (g water / g dry pasta)													
GF1	14.00 ± 0.71 d	3.22 ± 0.66 a	106 ± 3 f	1.68 ± 0.04 ab													
GF2	12.75 ± 0.35 bc	20.56 ± 1.22 f	49 ± 2 a	1.74 ± 0.05 bc													
GF3	13.25 ± 0.35 cd	8.21 ± 0.37 d	84 ± 8 cd	1.61 ± 0.04 a													
GF4	15.50 ± 0.71 e	29.82 ± 0.94 g	68 ± 6 b	1.81 ± 0.08 cd													
GF5	16.00 ± 0.71 e	19.95 ± 0.10 f	75 ± 4 bc	2.06 ± 0.08 e													
GF6	14.25 ± 0.35 d	4.83 ± 0.46 b	93 ± 6 de	1.83 ± 0.03 cd													
GF7	13.75 ± 0.35 cd	12.06 ± 0.20 e	107 ± 5 f	1.75 ± 0.04 bc													
GF8	11.75 ± 0.35 ab	6.98 ± 0.72 c	93 ± 7 de	1.88 ± 0.02 d													
W	11.25 ± 0.35 a	5.67 ± 0.20 b	94 ± 6 e	1.83 ± 0.10 cd													
	Hardness (g)	Adhesiveness (g·s)	Chewiness (g)	Resilience	Firmness (g)	Work of Shear (g·s)	Elastic Limit (g)	Elasticity (mm)									
GF1	5408 ± 348 a	7.8 ± 0.7 c	3747 ± 553 cd	0.42 ± 0.01 cd	231 ± 4 e	28 ± 1 cd	42 ± 2 f	36 ± 5 ab									
GF2	6560 ± 735 bc	7.9 ± 0.6 c	4317 ± 786 de	0.39 ± 0.02 c	166 ± 9 b	24 ± 1 bc	38 ± 2 e	36 ± 4 ab									
GF3	6254 ± 655 abc	7.6 ± 0.8 c	3295 ± 512 bc	0.35 ± 0.02 b	155 ± 8 b	26 ± 5 bcd	31 ± 2 c	56 ± 6 c									
GF4	6927 ± 844 cd	9.5 ± 0.7 d	5007 ± 434 e	0.44 ± 0.01 d	201 ± 10 cd	21 ± 3 ab	42 ± 1 f	73 ± 8 e									
GF5	6331 ± 487 abc	7.6 ± 0.3 c	3843 ± 543 cd	0.43 ± 0.02 d	268 ± 6 f	28 ± 1 d	43 ± 2 f	64 ± 3 d									
GF6	7795 ± 873 de	6.2 ± 0.4 b	3735 ± 558 cd	0.34 ± 0.02 b	161 ± 6 b	26 ± 1 cd	35 ± 2 d	34 ± 4 a									
GF7	8366 ± 875 e	6.1 ± 1.0 ab	4936 ± 443 e	0.30 ± 0.03 a	110 ± 8 a	18 ± 3 a	25 ± 1 b	34 ± 3 a									
GF8	7990 ± 533 de	5.1 ± 0.7 a	3224 ± 401 ab	0.30 ± 0.05 a	190 ± 9 c	22 ± 3 ab	20 ± 1 a	38 ± 3 ab									
W	5615 ± 598 ab	7.8 ± 0.5 c	2121 ± 239 a	0.29 ± 0.02 a	205 ± 4 d	28 ± 0 cd	31 ± 3 c	41 ± 4 b									

330 Table 3. Cooking quality indicators and texture parameters.

331 Mean ± standard deviation. Different letters within the same parameter differ significantly ($P < 0.05$).

332 OCT: Optimal cooking time; CL: Cooking loss; WA: Water absorption; SI: Swelling index.