https://doi.org/10.17221/168/2024-CJFS

Chemical composition, physical properties and sensory attributes of gluten-free pasta produced from acorn flour

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Citation: Rabeb L., Monceb C., Karima G., Manef A., Jamel M. (2026): Physical properties, texture and sensory attributes of gluten-free pasta produced from acorn flour. Czech J. Food Sci., 44: 101–111.

Abstract: The use of flours from the acorns of *Quercus ilex* and *Quercus coccifera* to produce gluten-free pasta was investigated in the current study. The latter evaluates the nutritional value, physical properties (minimum preparation time, water absorption index, cooking loss, and colour), textural properties (hardness, firmness, and stickiness), and sensory attributes of cooked rice pasta enriched with different dosages of acorn flour [25 g·(100 g)$^{-1}$ and 50 g·(100 g)$^{-1}$]. The results demonstrated that pasta produced from *Quercus ilex* acorn required the shortest cooking time, whereas pasta made from *Quercus coccifera* acorn exhibited the highest cooking losses. Pastes enriched with acorn displayed a more pronounced yellow colour. The combination of 50% rice flour and 50% acorn flour in pasta formulations significantly reduced cooking losses and yielded acceptable scores across all sensory attributes, resulting in the highest overall quality.

Keywords: *Quercus ilex*; *Quercus coccifera*; cooking quality; texture; nutritional composition; sensory evaluation

Pasta is an ancient food widely consumed throughout the world and is highly appreciated by all categories of consumers. Pasta is also one of the most popular and traditionally prepared simple grain foods. According to figures from the Italian Food Union, Italy stands as the foremost consumer of pasta globally, with an annual *per capita* consumption of 23 kg, significantly higher than Tunisia's 17 kg. The main raw material used in pasta manufacturing is durum wheat semolina, a product derived from initial milling process. Gluten, a complex protein present in wheat, barley and rye, has been identified in recent years as potential cause of digestive disorders and various diseases (Shan et al. 2002). Meeting the growing demand for gluten-free cereal-based products represents a significant challenge for food research and development. Although a gluten-free diet is currently the standard treatment, new research is underway to develop alternative treat-

https://doi.org/10.17221/168/2024-CJFS

ments, such as the use of enzymes to degrade gluten (Siegel et al. 2012).

However, these gluten-free products are low in essential nutritional compounds compared to wheat flour products. Among this category of products, a variety of cereal flours such as corn, rice, sorghum, are commonly utilised. Recently, acorns have attracted renewed interest as nutritious fruits, rich in minerals as calcium, iron, magnesium, potassium, phosphorus along with vitamins A and E (Li et al. 2015). They are also distinguished for their content of essential amino acids (Li et al. 2015).

Acorn flour has been a staple food in many cultures due to its nutritional value and availability. Indigenous peoples in North America, such as the Pomo and Miwok tribes, historically ground acorns into flour to make mush, bread, and soups after leaching them to remove bitterness (Anderson 2005). Similarly, in south of Korea, acorn flour is used to make dotori-muk, a traditional jelly-like dish that has been a part of Korean cuisine for centuries (An et al. 2022). In Mediterranean regions, acorn flour has been used in times of scarcity to prepare porridge and bread, reflecting its adaptability in various food traditions (Silva et al. 2016).

To enhance dietary options for celiac patients and promote their overall health, various efforts have focused on incorporating acorn flour into food products, namely bread (Purabdolah et al. 2020). Additionally, there have been attempts to introduce acorn flour into pastry products (Masmoudi et al. 2020).

Even though they can be found in nature, acorns are not currently used extensively. That is why the objective of this study is to evaluate the physical, sensory and textural properties of gluten-free pasta prepared from acorn flour. Although in the case of products made from flours other than wheat, the level of nutritional constituents depends strictly on the exact formulation, during this study we tested different rates of incorporation of acorn flour with rice flour for preparing pasta.

MATERIAL AND METHODS

Raw materials

Acorns of *Quercus ilex* (Q.I) and *Quercus coccifera* (Q.C) were harvested from the Nabeul region in northern Tunisia. The quality of the acorns was carefully checked before processing. Prior to use, the acorns were inspected to ensure they were free of contaminants. They were manually shelled and then carefully ground through a sieve with a mesh size of 250 µm to obtain a particle size ≥ 250 µm. In addition to the acorn flour, Tunisian white rice was sourced from a local market, and egg white powder (Fun Cakes, Casablanca, Aweg 20) was also included in the preparation.

Pasta production

As shown in Table 1, nine formulations of fresh pasta were developed. The gluten-free pasta formulations were processed manually.

Acorn flour and rice flour were mixed in proportions of 0 : 100, 25 : 75, 50 : 50, and 100 : 0 (acorn flour : rice flour w/w). These specific proportions were chosen to explore the effect of varying levels of acorn flour in the formulation of gluten-free pasta. The 0 : 100 ratio served as a control, representing a rice flour-based formulation, while the other ratios (25 : 75, 50 : 50, and 100 : 0) were selected to assess how the inclusion of acorn flour influences the texture and overall quality of the pasta. To prepare a protein-enriched pasta, we incorporated 6% of powdered egg white into our pasta production process: 30 g water·(100 g)$^{-1}$ of flour was added at room temperature and mixed for 15 min (3 min mixing, 10 min rest, another 2 min

Table 1. Composition of the tested formulations pasta

Acorn	Sample pasta	Acorn flour (%)	Rice flour (%)	Egg white powder (%)
	R	0	100	0
Quercus ilex	Qi	100	0	0
	3i	25	75	0
	4i	50	50	0
	5i	47	47	6
Quercus cocifera	Qc	100	0	0
	3c	25	75	0
	4c	50	50	0
	5c	47	47	6

https://doi.org/10.17221/168/2024-CJFS

of mixing). The ingredients were pressed in a stainless-steel bowl, allowing the various elements of the dough to hydrate uniformly. After kneading by hand for 10 min, a uniform dough was produced. To keep the dough from drying out, it was covered with plastic wrap. These portions of dough were flattened into thin sheets with a sheeter designed for making necessary pasta. The dough strands were cut into approximately 20 cm lengths. The obtained pasta was dehydrated for 30 min in an oven at 65 °C, cooled to room temperature and packed in plastic bags.

Chemical composition

Pasta that has been processed was examined for chemical composition using AACC protocols. The AACC method 08-01.01 was utilised to evaluate the ash content of the samples. Soxhlet extraction using *n*-hexane (AACC 30-10.01) was used to measure fat. The Kjeldahl method (AACC 46-10.01) was used to determine the protein content. The AOAC method 993.21 was used to determine dietary fibre content. The results were presented on a dry weight basis, and each analysis was carried out in triplicate.

Minimal preparation time (MPT). Ten grams of each pasta sample was hydrated in a 500 mL beaker, approximately 300 mL of water was heated to boiling. After each minute of hydration, a strand of pasta was removed and pressed between two sheets of Plexiglas. The MPT was determined by timing the disappearance of a white heart within the dough. Tests were carried out in triplicate.

Water absorption capacity. An amount of 10 g of each sample was hydrated in 500 mL of hot water (98 °C) in a covered container. Subsequently, the samples were drained for 5 min and weighed. The water retention capacity was calculated with the increase in the weight of the products before and after reconstitution.

Cooking loss. By totally evaporating the cooking water to constant weight in a hot air oven at 105 °C, we were able to determine which ingredients dissolve. A percentage of the sample's initial weight was determined by weighting the residue and computing the cooking loss. Triplicates of the tests were run.

Colour measurements

The colour parameters (L^*, a^* and b^*) of raw dough and cooked pasta were determined using a Minolta CR-300 Chromameter. The colour was measured at three points on the pasta surface before and after cooking. For cooked pasta, 200 mL of distilled water were used to cook the pasta strands for the ideal amount of time. Prior to measurement, the samples were drained and rinsed with cold water. Colour measurements were performed in triplicate. ΔEQ values were obtained by calculating the colour difference between the prepared pasta samples and the sample containing 100% *Quercus* acorn flour, while ΔER values were obtained by calculating the colour difference between the prepared pasta samples and the sample containing 100% rice flour:

$$\Delta E = \sqrt{\left(\Delta L*^2 + \Delta a*^2 + \Delta b*^2\right)} \quad (1)$$

Texture measurements

The textural properties of the cooked pasta, including shear force, cutting work, and adhesiveness were measured using texture analyser (TVT 6700, Perten, Sweden). After cooking the pasta for the optimal time, strands of pasta were cut into 5 cm lengths before being tested. The probe used was a steel cutting wire 90 mm long, at a constant speed of 1 $mm \cdot s^{-1}$ and a shear rate of 100%.

Sensory evaluation

The sensory evaluation of the cooked samples was performed to determine the acceptability of pasta enriched with acorn flour in comparison to the control made from rice flour. Each type of pasta was hydrated in hot water for the minimum preparation time necessary to ensure proper preparation. After cooking, the pasta was drained and served plain on white ceramic plates. These samples were then randomly presented to a panel of 40 members in tasting booths illuminated with white light. The role of the panel was to rate the products for appearance, taste, smell, texture and colour on a 5-point scale (1 = bad, 5 = good). Before starting the testing and between sampling, responders were instructed to rinse with water. Overall, pasta acceptability was rated on a verbal hedonic scale using a 9-point scale where 1 = dislike extremely, and 9 = like extremely. If their average scores for overall rating were greater than 5, the pasta was considered acceptable.

Statistical analysis

The experiments were carried out in triplicate and all data are expressed as the mean ± standard deviation (SD). Using IBM SPSS Statistics 25 (USA), the data were statistically analysed. Tukey's test was used to determine the significance of the means, and a difference was considered significant at $P < 0.05$.

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RESULTS AND DISCUSSION

Chemical composition

The chemical composition of all pasta samples was analysed using cooked pasta as previous studies have shown that cooking typically does not alter the macronutrient concentration (Tazart et al. 2016). Pasta made entirely from acorn flour displayed the lowest protein levels but had the highest fat and fibre content. The higher fat and fibre content may offer benefits such as improved digestive health and satiety, while the lower protein content may limit its role as a primary protein source in a balanced diet. The protein content of dry pasta enriched with egg white varied from 11.02 g·(100 g)$^{-1}$ for 5i pasta containing Q.I acorn flour to 10.78 g·(100 g)$^{-1}$ for 5c pasta containing acorn flour of Q.C The addition of egg white made it possible to improve the nutritional value of the pasta (5i and 5c) by almost 50% compared to pasta containing the same proportions of rice flour and acorn flour (4i and 4c). The ash content was 0.9% in the rice pasta (R), while it was greater than 2% in the case of Qi and Qc tasselled pasta. Enriching pasta with acorn flour also increased the fibre content compared to rice pasta (0.4% for R pasta compared to 1.4 and 1.8% for PQI and PQC pasta, respectively). The partial replacement of acorn flour with starch caused a decrease in the protein, fat and dietary fibre content (Table 2). This result is attributed to the high carbohydrate content of the starches. Additionally, it is important to note that starch from *Quercus* (oak) is not resistant to digestion by digestive enzymes, unlike some other starches (Cappai et al. 2013). This lack of resistance can impact its nutritional properties and digestibility, which is important for understanding its behaviour in various food applications. According to Martins et al. (2020), the addition of acorn flour from Q.C (with proportions of 30 and 60 g·(100 g)$^{-1}$ based on wheat flour) into the formulation of biscuits, induced a significant increase in the contents of phenolic compounds and the antioxidant activities of the final products.

Minimum preparation time

Overall, the time of cooking preparations ranged from 5.17 to 11.50 min (Table 3). The MPT decreases with the increase in acorn flour, similar to findings in studies on alternative pasta formulations with non-traditional flours such as quinoa and chickpea (Padalino et al. 2016). The control pasta R required the slowest preparation time (11.50 min). Less (statistically significant) time was required for products containing 100% acorn flour, especially *Quercus ilex* pasta (Qi) (Table 3). Although the cooking times of pasta containing 100% Q.I flour and 100% Q.C flour were similar ($P > 0.05$), they differed from the time determined for the control pasta (100% rice). The values reported in this study are similar to those observed by da Silva et al. (2016) for pasta prepared with a brown rice and corn meal (3.44 to 11.30 min) and lower for gluten-free pasta made with a mixture of sorghum-rice-corn flour and potato starch (11–15 min) (Ferreira et al. 2015). Thus, the type of flours used to produce pasta can influence its cooking time.

In addition, the starch content in rice flour is higher [more than 80% (Omar et al. 2016)] than that in acorn flour [about 55% (Taib and Bouyazz 2021)]. Therefore, increasing the content of rice flour increases the total starch content available in the mixture, potentially

Table 2. Nutritional value of pasta

Sample	Protein (%)	Fat (%)	Dietary fibre (%)	Ash (%)
R	7.24 ± 0.96	0.80 ± 0.12	0.40 ± 0.02	0.90 ± 0.30
Qi	3.23 ± 0.30	6.70 ± 0.23	1.40 ± 0.40	2.11 ± 0.23
3i	6.52 ± 0.41	2.23 ± 0.26	0.6 ± 0.09	1.12 ± 0.14
4i	5.26 ± 0.63	3.50 ± 0.35	0.87 ± 0.11	1.18 ± 0.20
5i	11.02 ± 0.72	3.46 ± 0.26	0.86 ± 0.21	1.54 ± 0.16
Qc	3.17 ± 0.16	5.10 ± 0.41	1.8 0± 0.50	2.33 ± 0.08
3c	6.49 ± 0.41	1.98 ± 0.12	0.68 ± 0.23	1.21 ± 0.09
4c	5.19 ± 0.62	2.19 ± 0.09	0.92 ± 0.15	1.31 ± 0.20
5c	10.78 ± 0.81	3.3 ± 0.18	0.89 ± 0.32	1.63 ± 0.12

R – 100% rice flour; Qi – 100% *Quercux ilex* (QI) flour; 3i – 25% QI flour + 75% rice flour; 4i – 50% QI flour + 50% rice flour; 5i – 47% QI flour + 47% rice flour + 6% egg powder; Qc – 100% *Quercux coccifera* (QC) flour; 3c – 25% QC flour + 75% rice flour; 4c – 50% QC flour + 50% rice flour; 5c – 47% QC flour + 47% rice flour + 6% egg powder

https://doi.org/10.17221/168/2024-CJFS

Table 3. Physical properties of formulations pasta

Sample pasta	Minimal preparation time (min)	Water absorption capacity [g·(100 g)$^{-1}$]	Cooking loss (%)
R	11.50 ± 0.95^{a}	113.16 ± 3.70^{e}	2.61 ± 0.40^{g}
Qi	5.17 ± 0.40^{f}	186.77 ± 3.90^{b}	3.17 ± 0.22^{g}
3i	10.36 ± 0.30^{ab}	125.55 ± 2.35^{d}	46.25 ± 0.95^{b}
4i	7.62 ± 0.08^{de}	193.65 ± 3.47^{b}	7.65 ± 0.06^{f}
5i	8.78 ± 0.34^{cd}	216.42 ± 0.71^{a}	2.45 ± 0.35^{g}
Qc	5.41 ± 0.26^{f}	132.47 ± 3.26^{cd}	21.81 ± 0.64^{d}
3c	9.25 ± 0.31^{bc}	115.28 ± 1.39^{e}	49.86 ± 2.39^{a}
4c	8.54 ± 0.07^{cd}	126.43 ± 1.90^{d}	40.26 ± 1.63^{c}
5c	6.66 ± 0.27^{e}	136.56 ± 0.89^{c}	11.11 ± 0.34^{e}

$^{a-f}$different letters in the same column indicate significant difference

R – 100% rice flour; Qi – 100% *Quercux ilex* (QI) flour; 3i – 25% QI flour + 75% rice flour; 4i – 50% QI flour + 50% rice flour; 5i – 47% QI flour + 47% rice flour + 6% egg powder; Qc – 100% *Quercux coccifera* (QC) flour; 3c – 25% QC flour + 75% rice flour; 4c – 50% QC flour + 50% rice flour; 5c – 47% QC flour + 47% rice flour + 6% egg powder

leading to extended cooking time. Conversely, the prolonged cooking time following starch pre-gelatinisation may be attributed to the enhanced capacity of the 'exposed' hydrophilic groups to bind water molecules and form a gel (Lai and Cheng 2004). Substituting rice flour with acorn flour is advantageous in terms of energy consumption because the longer cooking time results in increased energy expenses.

Water absorption capacity

Water absorption capacity ranged from 113.16 g·(100 g)$^{-1}$ for control rice pasta to 216.42 g·(100 g)$^{-1}$ for the 5i pasta containing 50 g·(100 g)$^{-1}$ *Quercus ilex* flour (Table 3). Pasta prepared with acorn flour absorbed more water compared to rice pasta (R). This phenomenon could be due to the slightly higher fibre content in acorn flour compared to rice flour, as the fibre components contain many polar groups that can retain water (Dharmaraj et al. 2016). Acorn flour contains a substantial fraction of water-extractable dietary fibres, particularly hemicelluloses and pectins, which interact effectively with water. These soluble fibres play a crucial role in improving water retention, resulting in acorn flour's higher ability to absorb moisture compared to rice flour. This property is especially important in gluten-free formulations, where moisture content and texture are critical. Studies by Szabłowska and Tańska (2021) have highlighted that the soluble fibre content in acorn flour contributes to a higher water-holding capacity, which is advantageous in various food applications, particularly those requiring enhanced texture and moisture retention. Proteins in acorn flour also contribute significantly to its water absorption capacity. The flour contains various proteins, including globulins and albumins (Shewry and Halford 2002), which are known to possess hydrophilic groups (amide -NH_2 and carboxyl -COOH). These hydrophilic properties allow the proteins to interact with water molecules, further enhancing the water retention capacity of acorn flour. Such proteins form hydrogen bonds with water, stabilising the hydration process and improving the texture of doughs and batters prepared from acorn flour. Water absorption capacity of R pasta [113.16 g·(100 g)$^{-1}$] is lower than that found by Bouasla et al. (2017) [181.53 g·(100 g)$^{-1}$] and the one by Mertz and Wang (2011) [122 g·(100 g)$^{-1}$] for rice pasta. This difference may be accredited to the variations in pasta preparation processes; pasta prepared by extrusion at high temperatures have higher water absorption capacities, as observed in the study by Bouasla et al. (2017). The low water absorption capacity for rice pasta compared to acorn pasta may be due to the higher starch content in the rice flour (Omar et al. 2016).

The water absorption index was significantly higher in pasta enriched with *Quercus ilex* flour compared to pasta supplemented with Q.C, flour (Table 3). This result can be explained by the difference in water absorption capacity of Q.I flour and Q.C flour. The water retention capacity of the flour glands was 3.2 g·g^{-1} and 1.2 g·g^{-1} for Q.I and Q.C, respectively (Lassoued et al. 2022). The samples enriched with egg whites (5i and 5c) revealed higher absorbance percentages probably because they had the highest protein content. Protein is a key factor responsible for shaping the pasta's struc-

https://doi.org/10.17221/168/2024-CJFS

ture during processing, as discussed by Petitot et al. (2009). Moreover, it has the ability to readily absorb and retain water.

Cooking loss (CL)

The ability of pasta to resist disintegrating while cooking is expressed by cooking loss. Up to 6% wastage, it is considered fairly good, up to 8%, it is considered regular, and above 10%, it is considered poor. In this study, pasta produced with *Quercus ilex* acorn flour (Qi) and rice flour (R) as well as pasta enriched with 50% *Quercus ilex* acorn flour (5i) had the lowest losses (2.61, 3.17 and 2.4% for R, QI and 5i, respectively) (Table 3). The higher values of CL were observed by Marti et al. (2010), for pasta produced from rice (15.9%).

Regarding traditional wheat pasta, some researchers report cooking losses of 4.4% and 6.4% for commercial pasta (Martinez et al. 2007). Indeed, the solubilisation of bound gelatinised starch from the product's surface is the primary cause of CL seen in gluten-free pasta. The strength of the retrograded starch network enclosing the gelatinised starch and the extent that surrounds the gelatinised starch, along with the degree of starch gelatinisation are also contributing factors. Since there is no gluten network, starch polymers are not as effectively trapped within the matrix, leading to a gluten-free product with a high CL. However, the low cooking loss in the case of 5i pasta can be explained by the addition of egg powder, which might support and preserve the pasta's structural integrity while it cooks.

In this study, pasta produced with Q.C flour showed the highest cooking loss [Qc: 52 g·(100 g)$^{-1}$], which is undesirable for commercial production since disposing of starchy water as wastewater can be costly.

Colour of gluten-free pasta

One crucial factor in determining the quality of pasta is its colour. Table 4 displays the colour profile of the hydrated and dry pasta. Concerning the colour of the pasta, it is evident that as the amount of acorn flour increased, the L^* value significantly dropped ($P < 0.05$). Dry pasta containing acorn flour was much darker ($P < 0.05$) than dry rice pasta (R). The obtained results accord well with those of Martins et al. (2020) and Korus et al. (2015), indicating a decrease in the L^* parameter in correlation with the increasing level of acorn supplementation in bread. Additionally, Korus et al. (2017) also demonstrated a reduction in the L^* parameter in biscuits when incorporating acorn flour. This characteristic is particularly significant for gluten-free pasta because such products often have paler colours

Table 4. Dry and hydrated gluten-free pasta's colour profile

Sample	Dry pasta					Hydrated pasta				
	a^*	b^*	L^*	ΔEQ	ΔER	a^*	b^*	L^*	ΔEQ	ΔER
R	1.38 ± 0.22^{dA}	8.00 ± 0.72^{cA}	94.36 ± 1.24^{aA}	45.88		1.79 ± 0.20^{eA}	13.92 ± 0.85^{cdB}	78.67 ± 1.27^{aB}	33.12	
Qi	11.07 ± 2.85^{abA}	25.13 ± 2.60^{bA}	52.91 ± 3.99^{eA}		45.88	7.63 ± 0.27^{aA}	21.16 ± 0.45^{aA}	46.89 ± 0.63^{eA}		33.12
3i	5.46 ± 2.48^{cA}	24.92 ± 3.63^{bA}	75.25 ± 4.71^{bA}	23.03	25.85	5.06 ± 0.00^{dA}	17.20 ± 0.0^{bcB}	65.00 ± 0.00^{bB}	18.71	14.44
4i	8.21 ± 0.71^{bcA}	31.81 ± 0.47^{aA}	63.78 ± 1.56^{cA}	13.08	39.35	6.24 ± 0.43^{bA}	18.53 ± 2.97^{abB}	60.88 ± 1.23^{cA}	9.25	18.91
5i	9.30 ± 0.51^{bA}	26.05 ± 2.12^{bA}	55.59 ± 1.70^{deA}	3.34	43.492	4.88 ± 0.07^{dB}	13.91 ± 0.47^{cdB}	51.92 ± 0.97^{dB}	13.27	26.93
Qc	13.70 ± 0.46^{aA}	24.43 ± 2.07^{bA}	54.84 ± 2.03^{eA}		44.53	8.26 ± 0.31^{aB}	21.91 ± 0.25^{aA}	47.07 ± 0.25^{eB}		33.24
3c	7.39 ± 0.79^{bcA}	21.67 ± 0.37^{bA}	74.31 ± 2.34^{bA}	20.65	24.99	5.87 ± 0.25^{bcA}	17.33 ± 1.27^{bcB}	60.07 ± 1.90^{cB}	13.98	20.59
4c	8.92 ± 0.31^{bcA}	32.28 ± 0.98^{aA}	62.71 ± 1.54^{cdA}	12.09	40.59	6.32 ± 0.35^{bA}	19.57 ± 1.03^{abB}	61.24 ± 1.01^{cA}	14.49	18.87
5c	9.43 ± 0.28^{bA}	26.38 ± 0.97^{bA}	55.30 ± 1.74^{eA}	4.72	43.91	5.28 ± 0.27^{cdB}	13.56 ± 0.51^{dB}	52.45 ± 0.71^{dB}	10.38	26.45

$^{a-e}$different letters in the same column indicate significant difference between values ($P < 0.05$); ^{A,B}different letters in the same row indicate significant difference between attribute values (a^*, b^*, L^*); The color difference within the same sample not having been quantified, the corresponding cells have been highlighted in grey

R – 100% rice flour; Qi – 100% *Quercux ilex* (QI) flour; 3i – 25% QI flour + 75% rice flour; 4i – 50% QI flour + 50% rice flour; 5i – 47% QI flour + 47% rice flour + 6% egg powder; Qc – 100% *Quercux coccifera* (QC) flour; 3c – 25% QC flour + 75% rice flour; 4c – 50% QC flour + 50% rice flour; 5c – 47% QC flour + 47% rice flour + 6% egg powder; ΔEQ – the colour difference between the prepared pasta samples and the sample containing 100% *Quercus* acorn flour; ΔER – the colour difference between the prepared pasta samples and the sample containing 100% rice flour

https://doi.org/10.17221/168/2024-CJFS

compared to traditional wheat-based counterparts. This light colour is generally considered as a drawback in gluten-free bread.

With respect to the parameters a^* and b^* of the pasta, a significant increase ($P < 0.05$) can be observed with the incorporation of acorn flour, which suggests a more intense red colour compared to green, and a predominance of yellow over blue, respectively. The greater yellowness shown by pasta containing 50% acorn flour (4i and 4c) is potentially advantageous, as yellow colour in pasta is generally desired, as noted by Ohm et al. (2008). The colour of pasta is greatly influenced by the raw materials used, the characteristics of the flour or semolina, including carotenoids and protein composition.

Pasta that has been hydrated has a stronger hint of red colour than pasta that has not been hydrated. The disintegration and breakdown of pigments caused by hot water is probably the cause of the hydrated pasta's less red hue. Furthermore, the rice control sample's lightness significantly decreased (from 94.36 to 78.67) after cooking. Tazart et al. (2016) have observed comparable findings for control rice pasta, pasta enriched with legumes, and pasta that has been supplemented with chickpea flour.

The human eye can only detect the difference in colours if $\Delta E > 5$ (Tazart et al. 2016). When comparing the control rice pasta with the acorn pasta, it can be noticed that the difference between the pasta colours is remarkably high. The ΔE between the dry pasta containing acorn flour and the rice control ranged from 25.8 to 45.8, increasing with the increase in acorn flour content. These values indicate that the consumer would distinguish between the samples being compared. However, the difference between the two acorn pastas (Q.I and Q.C) with samples 5c and 5i, was $\Delta E < 5$ or almost in the perception of the threshold of the human eye. The ΔE values of the samples containing the acorn flour became lower after the pasta was cooked, which was mainly due to the significant decrease in b^* and L^* of the acorn after cooking.

Texture of gluten-free pasta

The textural characteristics play a vital role in determining consumer satisfaction. The results of pasta texture are presented in Table 4. Pasta cutting force serves as an indirect measure of pasta hardness. Because cutting is often associated with 'pasta firmness', the parameter of pasta cutting force is commonly used to assess it (Bouasla et al. 2017). The pasta containing 100% acorn flour has the lowest hardness (1.029 N and 0.960 N for the Qi and Qc pasta, respectively). Cutting force was higher for rice pasta (R) than pasta prepared by combining acorn flour and rice flour [except pasta enriched with egg white (5i and 5c)]. The same trends were observed by Bouasla et al. (2017) for the fortification of rice flour with pulse flour. The fibrous fractions in pulse flour can result in the development of fissures or discontinuities inside the pasta strand, weakening the pasta's structural integrity (Petitot et al. 2010). As mentioned in Table 2, acorn pasta has a higher fibre content compared to rice pasta.

From the results of Table 5, it is evident that incorporating Q.I acorn flour into the pasta formulation, while decreasing the proportion of rice flour, increases the firmness of the pasta. According to Tsatsaragkou et al. (2016) the fibre is a key structural activator, whose level plays a significant function. Fibers have a favourable

Table 5. Textural properties of gluten free pasta

Sample pasta	Cutting force (N)	Firmness (mJ)	Adhesiveness (mJ)
R	1.234 8 ± 0.12	262.89 ± 6.41	0.14 ± 0.01
Qi	1.068 2 ± 0.08	327.77 ± 12.13	0.56 ± 0.04
3i	1.195 6 ± 0.09	273.08 ± 9.14	5.32 ± 0.07
4i	1.078 ± 0.11	353.45 ± 11.89	0.12 ± 0.01
5i	2.949 8 ± 0.07	707.66 ± 23.4	7.59 ± 0.08
Qc	0.960 4 ± 0.13	233.30 ± 14.5	0.61 ± 0.03
3c	1.117 2 ± 0.12	272.50 ± 7.23	10.10 ± 0.11
4c	1.048 6 ± 0.08	223.46 ± 11.9	1.29 ± 0.05
5c	2.214 8 ± 0.04	753.52 ± 8.34	2.88 ± 0.02

R – 100% rice flour; Qi – 100% *Quercux ilex* (QI) flour; 3i – 25% QI flour + 75% rice flour; 4i – 50% QI flour + 50% rice flour; 5i – 47% QI flour + 47% rice flour + 6% egg powder; Qc – 100% *Quercux coccifera* (QC) flour; 3c – 25% QC flour + 75% rice flour; 4c – 50% QC flour + 50% rice flour; 5c – 47% QC flour + 47% rice flour + 6% egg powder

effect on texture, enhancing stiffness and cohesiveness due to their ability to bind water, produce gels, make imitations, and thicken materials.

The decrease in the cutting force and cutting work of Q.C acorn pasta was observed by increasing the percentage of *Quercus* flour. The addition of *Quercus ilex* and Q.C flours had different impacts on the textural properties of rice pasta. The incorporation of Q.I flours gave much firmer pasta. On the other hand, the enrichment with Q.C flour produces pasta with a softer texture, less firm, and less resistant to disintegration during cooking. The results of this study can be attributed to the disparity in composition between the two varieties. In the literature, Q.C flour has been proven to contain a higher amylose content in its starch fraction, as indicated by Lassoued et al. (2022). According to Mertz and Wang (2011), recipes with the highest amylose content give more pasta. The incorporation of high amylose starch could lead to increased cooking loss and decreased firmness of rice pasta. Conversely, including low amylose starch in rice flour would have the opposite effects (Mertz and Wang 2011).

The results show that adding egg white to pasta recipes improves the hardness and firmness of the pasta, for both varieties of acorn flour, which is in agreement with the findings obtained by Martins et al. (2020).

Adding acorn flours to recipes has increased the stickiness of pasta. It went from 0.14 mJ for rice pasta to more than 10 mJ for 3c pasta. This increase in stickiness can be attributed either to a larger fibre content or a higher solubility of the substance's pulps released during hot water hydration. This result aligns with those found for the loss of cooking, in which pasta enriched with egg white demonstrated increased adhesiveness. According to Tudorica et al. (2002), the protein matrix gradually breaks down during the cooking process, releasing extrudates during starch gelatinisation. This process contributes to enhancing cohesiveness and stickiness on the surface of cooked pasta.

Sensory attributes. The results of the hydrated pasta's sensory analysis are shown in Table 6. The majority of the pasta received high marks for the appearance. These various pasta samples were characterised by the absence of surface cracks (Figure 1) and the good resistance to the cooking process except for the samples (3i and 3c) containing 25% acorn flour that had high disintegration and loss during cooking. The pasta with 50% acorn flour attained the top ratings for taste. Elevated acorn flour levels brought about an astringent sensation, while there was no bitterness detected in any of the pasta types. This result accords well with that found for the biscuit enriched with acorn flour. Indeed, Pasqualone et al. (2019) showed that an astringent sensation appeared when acorn flour was added, but it was only given a very low rating.

According to Korus et al. (2015), the samples of bread enriched with 20% and 40% acorn flour were much better in taste than those enriched with 60%. This proves that the addition of acorn flour (greater than 40%) negatively impacts sensory parameters and overall acceptance of gluten-free bread. However, a sample containing up to 50% acorn flour enriched with egg white had similar taste scores to a sample containing 50% acorn flour in egg white, indicating that the addition

Table 6. Sensory analysis and general acceptability of gluten-free pasta (n = 20)

Sample	Appearance[1]	Flavour[1]	Taste[1]	Stickiness[1]	Texture	Colour[1]	Overall acceptability[2]
R	3.00 ± 0.72^{d}	2.05 ± 0.60^{e}	3.20 ± 0.77^{b}	4.65 ± 0.50^{a}	3.55 ± 0.82^{c}	3.10 ± 1.07^{c}	5.15 ± 0.99^{c}
Qi	4.05 ± 0.60^{bc}	4.70 ± 0.66^{a}	3.35 ± 0.81^{b}	4.45 ± 0.51^{a}	2.80 ± 0.69^{d}	3.45 ± 1.39^{bc}	5.55 ± 0.88^{c}
3i	1.50 ± 0.69^{e}	3.00 ± 0.72^{d}	3.00 ± 0.79^{b}	1.60 ± 0.75^{c}	2.25 ± 0.64^{d}	4.45 ± 0.68^{a}	4.05 ± 0.82^{d}
4i	4.10 ± 0.64^{bc}	4.05 ± 0.60^{b}	4.40 ± 0.75^{a}	4.70 ± 0.47^{a}	4.10 ± 0.55^{abc}	3.85 ± 0.67^{abc}	8.30 ± 0.66^{a}
5i	4.80 ± 0.52^{a}	3.90 ± 0.55^{bc}	4.60 ± 0.68^{a}	2.90 ± 0.79^{b}	4.70 ± 0.47^{a}	4.50 ± 0.76^{a}	8.55 ± 0.69^{a}
Qc	3.85 ± 0.74^{c}	4.85 ± 0.36^{a}	3.20 ± 0.76^{b}	3.35 ± 0.67^{b}	3.65 ± 0.93^{bc}	3.65 ± 0.93^{abc}	5.35 ± 1.04^{c}
3c	1.60 ± 0.68^{e}	3.30 ± 0.80^{cd}	2.80 ± 0.83^{b}	1.55 ± 0.69^{c}	2.30 ± 0.73^{d}	4.20 ± 0.83^{ab}	3.05 ± 0.82^{e}
4c	3.95 ± 0.60^{bc}	4.00 ± 0.56^{b}	4.40 ± 0.68^{a}	2.90 ± 0.79^{b}	4.00 ± 0.46^{bc}	4.50 ± 0.76^{a}	6.65 ± 0.81^{b}
5c	4.55 ± 0.76^{ab}	4.45 ± 0.82^{ab}	4.60 ± 0.60^{a}	2.95 ± 0.89^{b}	4.25 ± 0.55^{ab}	4.25 ± 1.02^{ab}	8.40 ± 0.75^{a}

[1]5-point scale; [2]9-point hedonic scale; [a–e]different letters indicate significant difference between means in the same column ($P < 0.05$)

R – 100% rice flour; Qi – 100% *Quercux ilex* (QI) flour; 3i – 25% QI flour + 75% rice flour; 4i – 50% QI flour + 50% rice flour; 5i – 47% QI flour + 47% rice flour + 6% egg powder; Qc – 100% *Quercux coccifera* (QC) flour; 3c – 25% QC flour + 75% rice flour; 4c – 50% QC flour + 50% rice flour; 5c – 47% QC flour + 47% rice flour + 6% egg powder

https://doi.org/10.17221/168/2024-CJFS

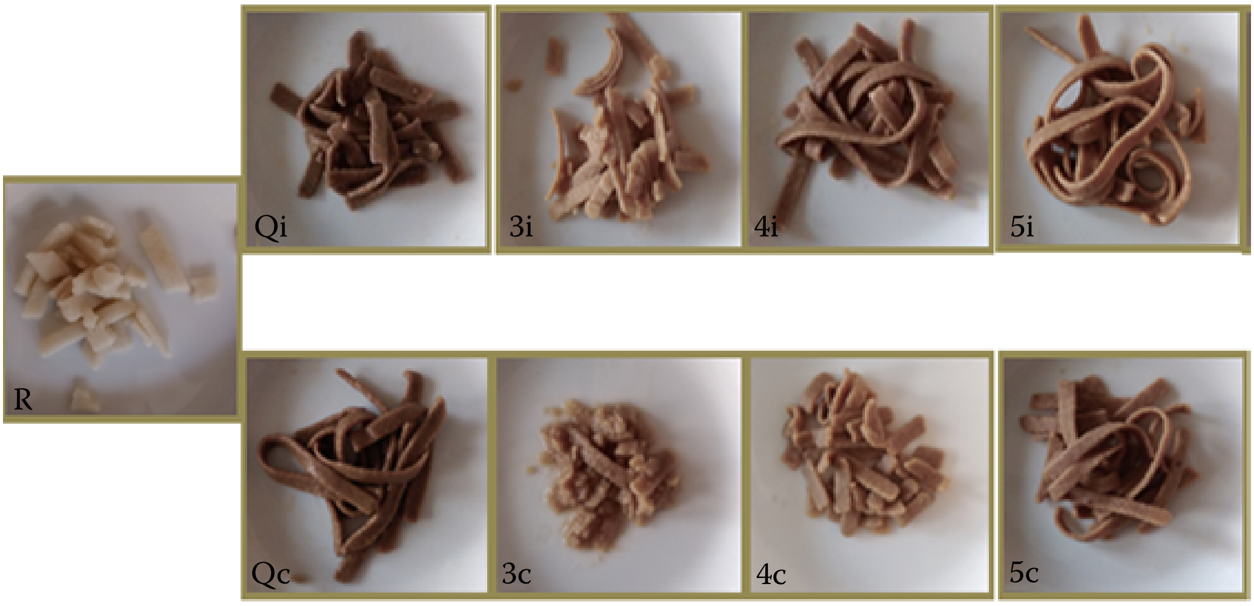

Figure 1. Gluten-free pasta after hydration

R – 100% rice flour; Qi – 100% *Quercux ilex* (QI) flour; 3i – 25% QI flour + 75% rice flour; 4i – 50% QI flour + 50% rice flour; 5i – 47% QI flour + 47% rice flour + 6% egg powder; Qc – 100% *Quercux coccifera* (QC) flour; 3c – 25% QC flour + 75% rice flour; 4c – 50% QC flour + 50% rice flour; 5c – 47% QC flour + 47% rice flour + 6% egg powder

of egg white did not have any significant effect on taste. Pasta products (Qi and Qc) containing only acorn flour had the highest scores for flavour.

Moreover, all pasta samples showed acceptable colour scores, with pasta containing 25 g·(100 g)$^{-1}$ and 50 g·(100 g)$^{-1}$ acorn flour having the highest scores for colour ($P < 0.05$), which is confirmed by colour measurement. The pasta control colour (R) was less favourable to the judges probably because rice flour contains a lower content of carotenoid content, leading to a less attractive appearance after cooking. This finding aligns with those found by Korus et al. (2015) in their study on incorporating acorn flour in bread preparation. Their research demonstrated that the application of acorn flour resulted in better consumer acceptance compared to the control sample. The pasta colour was also more favourably received when acorn flour was added to the bread, which is likely due to the reduction in paleness, which is often associated with highly refined and less wholesome products.

Korus et al. (2015) further noted that in terms of consumer preference, replacing 20–40% of the recipe with acorn flour scored higher than rice bread. The stickiness and texture scores were at their lowest values for products containing 25% acorn flour. However, it is worth mentioning that the 5i sample displayed a texture closest to the ideal, as determined by each panellist's individual assessment using the provided sensory test scale.

The overall acceptability was assessed based on the scores of various characteristics. According to Table 6, all the pasta products received acceptable scores (values > 5), indicating that the sensory parameters were widely appreciated by the tasters. Samples containing 50% acorn flour (4i, 5i and 5c) were the most appreciated, while the 3c sample had a lower level of acceptance. The addition of 25% acorn flour significantly reduced scores for most sensory attributes.

CONCLUSION

The present study explored the utilisation of *Quercus* acorn flour in the gluten-free pasta production. It revealed that conventional rice pasta had the longest preparation time, while pasta made entirely from acorn flour required a significantly shorter duration, making it more time-efficient and cost-effective. Water absorption index was significantly higher in pasta enriched with Q.I flour compared to Q.C flour. Pasta produced with Q.C flour underwent, which were effectively reduced by using a 50% acorn flour and 50% rice flour combination. The addition of 6% powdered egg white further enhanced texture, minimised cooking losses, and increased absorbance percentages.

https://doi.org/10.17221/168/2024-CJFS

However, when incorporating 25% acorn flour, the results were less favourable compared to the 50% blend, resulting in higher cooking losses and increased stickiness. Notably, all pasta variants containing acorn flour exhibited a darker colour compared to those made exclusively with rice flour.

Sensory evaluations revealed that pasta made from 100% *Quercus* acorn flour was particularly well-received due to its distinct and appreciated flavours. These results suggest that acorn flour can serve as a viable alternative to rice flour in gluten-free pasta production. Among the various tested formulations, the 50/50 blend of acorn flour and rice flour emerged as the most recommended choice by the panel of testers.

Future studies could investigate the use of other technological methods to enhance pasta texture, such as the application of high-pressure processing (HPP), which has shown promising results in improving the texture and quality of gluten-free pasta by modifying the starch network. Additionally, exploring the use of novel hydrocolloids, such as alginates or carrageenan, could improve the structure and elasticity of gluten-free pasta.

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Received: September 1, 2024
Accepted: March 21, 2026
Published online: April 29, 2026