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Improving the nutritional performance of gluten-free pasta with potato peel autohydrolysis extract

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ABSTRACT

The potato processing industry produces peels, a good source of fibres, minerals and antioxidants, which could be recovered and used in the production of added-value products, such as gluten-free (GF) foods especially designed for the celiac population.

This work is focused on the application of the bioactive fraction extracted from potato peels into GF pasta. Subcritical water extraction (autohydrolysis, AH) was performed on potato peel, and the obtained AH liquid extract was characterized in terms of total phenolic content and antioxidant activity. The selected AH temperature (220 °C at 2.2 MPa) was applied to peels from Kennebec, Neiker and Agria potato varieties, and the Agria extract was selected for application in GF pasta, as this was the one with higher antioxidant activity.

The impact of Agria potato peel autohydrolysis extract on the nutritional composition and cooking quality of pasta was assessed. Results confirmed that the GF pasta enriched with potato peel extract presented suitable technological properties, coupled with attractive colour and with increased total phenolic content and antioxidant activity, which can contribute to improve the offer of GF products in the market.

1. Introduction

The development of gluten-free products with balanced nutritional quality is a trend of the food industry. Also, sustainability concerns are in todays' agenda, driving the better use of resources to the development of added-value foods (e.g. Iriondo-DeHond et al., 2019; Pal & Suresh, 2016).

Potatoes are the fourth most important food crop in the world, with an estimated production of 368 million tonnes in 2018. China is the biggest producer of potatoes worldwide, with about one third of the world's potatoes produced in China and India (FAOSTAT, 2019). Potato cultivated globally belongs to just one botanical species, *Solanum tuberosum* L., with thousands of varieties with great differences in size, shape, colour, texture, flavour and cooking characteristics (FAO, 2008).

During harvest and storage of potatoes, up to 30% are discarded due to undersized potatoes, which currently have a low added value being used primarily for animal feed (Priedniece, Spalvins, Ivanovs, Pubule, & Blumberga, 2017). Also, the world potato sector is undergoing major changes, with an increase in potato processed products such as fries, chips, mashed and canned potatoes which generate large amounts of peels and outer flesh layers. Besides, potato is the major starch source since the extraction procedure is simpler in comparison to cereal starches (Torres et al., 2020; Torres, Chenlo, & Moreira, 2018). The by-products of potatoes generated from the extensive applications in various industries represent rich sources of phenolic compounds and oligosaccharides, and their biological properties have been extensively studied (Akyol, Riciputi, Capanoglu, Caboni, & Verardo, 2016; Gientka, Aleksandrzak-Piekarczyk, Bzducha-Wróbel, Synowiec, & Błazejak, 2019; Jeddou et al., 2018). Therefore, the valorisation of potato by-products is crucial to the sustainability of the potato industry and can add value to products such as gluten-free foods, being reintroduced into the food value chain, a good bioeconomy practice.

Following the current trends in green chemistry, using water as the only extraction agent (Díaz-Reinoso, González-Muñoz, & Domínguez, 2017), the use of green technologies to extract functional components from potato peel could be an alternative to value this resource. Water-based extraction is food compatible, non-expensive, and environmentally friendly but has low selectivity with low extraction efficiency (Flórez-Fernández, Torres, González-Muñoz, & Domínguez, 2019; López-Hortas et al., 2018). To increase hydroextraction the autohydrolysis (AH) process can be performed using high temperature and pressure to boost aqueous extractions efficiency. This technology

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allows the formation of new compounds with antioxidant activity due to Maillard and caramelization reactions, and also the extraction of apolar components as a consequence of the lower water polarity (Plaza, Amigo-Benavent, del Castillo, Ibáñez, & Herrero, 2010; Rajauria, Jaiswal, Abu-Ghannam, & Gupta, 2010). The authors of the present study have expertise in the use of this technology in the recovery of bioactive-rich extracts from several matrices, namely mushrooms (Huamán-Leandro et al., 2020), seaweeds (Fradinho et al., 2020) and potato peel (Torres et al., 2020).

In this context, the development of gluten-free pasta nutritionally enriched in bioactive compounds from potato peel extract was studied, in line with the sustainable and healthy food trends.

2. Materials and methods

2.1. Materials and sample preparation

Low-size discarded potatoes from three Galician (Spain) varieties (Kennebec, Agria and Neiker) were kindly provided by INORDE (Instituto Ourensán de Desenvolvemento Económico). Rice flour (Ceifeira, Dacsa Atlantic, lot 3411/18) and *Psyllium* husk from India (Solgar, lot 107028-01, USA) were purchased in the local market. *Psyllium* was milled (Pulverisette 14 Premium, Fritsch, Germany) and sieved to 160–315 μm particles.

2.2. Subcritical water extraction and extract characterization

The potato peel coarse milled fraction (0.25–2 mm) was subjected to hydrothermal processing (autohydrolysis) with compressed hot water, in a pressurized reactor (Parr 4848, Illinois, USA), operating at around 2.2 MPa. The most abundant potato variety (Kennebec) was used for optimization of the autohydrolysis conditions: the ground peel contacted with water at a liquid:solid ratio of 15:1 (w/w), and a temperature sweep from 160 to 220 °C was performed. The conditions used for autohydrolysis were selected based on the results previously reported by Torres et al. (2020).

Then, the selected temperature (220 °C) was applied to the other potato varieties, namely Agria and Neiker. The liquid fraction was separated by filtration and it was stored at 4 °C until further analysis, within a week.

Colour determination, total phenolic content (TPC) and antioxidant activity evaluation were performed in all autohydrolysis liquid extracts as described in Sections 2.5 and 2.7.

2.3. Fresh pasta preparation and sampling

Potato peel autohydrolysis liquid extract was processed with *Psyllium* husk: 4% w/w, dry basis (d.b.) at 40 °C, 10 min to obtain a gel, at the conditions earlier described by Fradinho, Soares, Niccolai, Sousa, and Raymundo (2020). This gel was mixed with rice flour (50:50 ratio) in a thermoprocessor (Bimby TM31, Vorwerk, Wuppertal, Germany) at 25 °C for 3 min. Then, the dough was sheeted and laminated as tagliatelle using a benchtop pasta machine (Atlas 150 Wellness, Marcato, Italy), covered with aluminium foil, and placed in an air oven at 25 °C for 15 min to equilibrate the structure. A control sample (without AH extract) was also prepared using the same procedure.

All pasta samples (uncooked and cooked) were lyophilized (Scanvac Coolsafe 55-4, Labogene, Allerød, Denmark), crushed into powder and stored at 20 °C in a desiccator until further chemical analysis. Physical analyses (colour, texture and rheology) were performed immediately after preparation.

2.4. Cooking quality parameters

Pasta was cooked for 2 min as previously optimized by the authors (Fradinho, Raymundo, Sousa, Domínguez, & Torres, 2019) and water absorption, swelling power and cooking loss parameters were assessed following the AACC method 66-50 (AACC, 1999a) procedure already described in Fradinho, Sousa, and Raymundo (2019). Each determination was performed at least three times.

2.5. Colour measurements

The colour measurements of autohydrolysis extracts, and raw and cooked pasta samples were performed instrumentally using a CR-400 colorimeter (Minolta, Japan) with standard illuminant D65 and a visual angle of 2°. The colour parameters (L*, a* and b*) were accessed by CIELAB system, where L* defines lightness, and a* (degree of redness/greenness) and b* (degree of yellowness/blueness) are the chromaticity parameters. The colour stability upon cooking was determined by the total colour difference between raw and cooked pasta samples ($\Delta E^*_{raw} - \Delta E^*_{cooked}$) and between potato enriched pasta (PPE) and the control ($\Delta E^*_{control} - \Delta E^*_{PPE}$), according to Eq. (1).

$$\Delta E^* = [(L^*_{raw} - L^*_{cooked})^2 + (a^*_{raw} - a^*_{cooked^2}) + (b^*_{raw} - b^*_{cooked})^2]^{1/2} \quad (1)$$

The measurements were conducted under the same light conditions, using a white standard (L* = 94.61, a* = −0.53, b* = 3.62), under artificial fluorescent light at 20 ± 1 °C and replicated at least 6 times.

2.6. Nutritional composition

Raw and cooked pasta samples were analysed for their moisture content according to AACC method 44-15.02 (AACC, 1999b) and ash NP518 (1986), based on gravimetric methods. Total lipid analysis was carried out according to the Portuguese standard method NP4168 (1991) and protein content was determined by the Kjeldahl method following the (ISO 20483, 2006) using nitrogen conversion factor 5.95 (FAO, 2003) to obtain the pasta crude protein content.

Soluble, insoluble, and total dietary fibre contents of cooked pasta samples were evaluated according to AOAC 991.43 (1998) with the specific modifications for *Psyllium* fibre suggested by Lee, Rodriguez, and Storey (1995).

Mineral (Na, K, Ca, Mg, P, S, Fe, Cu, Zn, Mn, I) analysis was carried out by inductively coupled plasma (ICP) spectrometry (iCAP Spectrometer equipped with ASX-520 AutoSampler, Thermo Scientific, Waltham, MA, USA) following the procedure described in (Fradinho et al., 2019).

Carbohydrate content was determined by difference to 100% of main constituents (moisture, ash, protein and lipids). All chemical analyses were carried out at least in triplicate.

2.7. Determination of bioactive compounds

Raw and cooked pasta samples were subjected to extraction (in duplicates) following the procedure described by Sant'Anna, Christiano, Marczak, Tessaro, and Thys (2014). 1 g of lyophilized sample was mixed with 50 mL ethanol/water (50:50), incubated at 60 °C/1 h, under magnetic stirring, and filtered with Whatman filter paper n.1. The liquid extracts were recovered and used for total antioxidant activity (AA) and total phenolic content (TPC) measurements. All the following spectrophotometric methods were performed in triplicate in a Unicam UV4 spectrophotometer (Thermo Scientific, Waltham, MA, USA). Two blank assays, one without sample and the other without reagents were also performed in each method.

2.7.1. Total phenolic content

Total phenolic content was analysed by the Folin-Ciocalteu method using gallic acid (20–120 mg/L) as standard (Singleton & Rossi, 1965). Liquid extracts (250 μL) were mixed with distilled water (1875 μL), Folin-Ciocalteu's phenol reagent (125 μL) and sodium carbonate (250 μL, 10%, w/v). Samples were incubated in darkness at 20 °C for

Table 1
Characterization of liquid extracts obtained from autohydrolysis of the three varieties of potato peels: Kennebec, Neiker and Agria.

Potato variety	Kennebec				Neiker	Agria
Final temperature (°C)	160	180	200		220	
TPC (g GAE/L)	0.34 ± 0.00^{f}	0.55 ± 0.02^{e}	0.87 ± 0.02^{d}	1.34 ± 0.01^{a}	0.93 ± 0.02^{c}	1.02 ± 0.03^{b}
Antioxidant Activity (mmol TEAC/L)						
ABTS	0.29 ± 0.02^{e}	3.14 ± 0.39^{d}	5.80 ± 0.75^{c}	9.76 ± 0.05^{b}	14.38 ± 0.85^{a}	15.68 ± 0.26^{a}
DPPH	0.54 ± 0.01^{d}	0.67 ± 0.01^{b,c}	0.70 ± 0.02^{b,c}	0.71 ± 0.01^{b}	0.66 ± 0.01^{c}	0.79 ± 0.01^{a}
Colour						
L*	33.03 ± 2.37^{a}	35.4 ± 1.72^{a}	25.42 ± 1.48^{b}	19.73 ± 1.38^{c}	20.88 ± 1.50^{c}	20.23 ± 0.58^{c}
a*	0.62 ± 0.43^{c}	0.72 ± 0.66^{c}	4.79 ± 0.61^{b}	7.70 ± 1.16^{a}	7.57 ± 0.82^{a}	6.61 ± 0.78^{a,b}
b*	1.07 ± 0.67^{b}	4.62 ± 0.90^{a}	2.40 ± 0.51^{a,b}	2.35 ± 1.68^{a,b}	2.71 ± 1.07^{a,b}	−5.13 ± 0.88^{c}

Data are presented as mean ± standard deviation. Different letters in the same row correspond to significant differences ($p < 0.001$, one-way ANOVA, *post-hoc* Tukey test). TPC: Total phenolic content; DPPH: α,α-diphenyl-b-picrylhydrazyl; ABTS: 2,2-azinobis(3-ethyl-benzothiazoline-6-sulfonate); GAE: gallic acid equivalent; TEAC: Trolox Equivalent Antioxidant Capacity.

1 h, before absorbance measurements (765 nm). The results were expressed as milligram GAE (gallic acid equivalent) per gram of sample (dry basis).

2.7.2. Antioxidant activity

The ABTS radical cation ($ABTS^{\cdot+}$) [2,2-azinobis(3-ethyl-benzothiazoline-6-sulfonate)] scavenging activity was determined according to Re et al. (1999). Briefly, liquid extract (30 μL) and $ABTS^{\cdot+}$ solution (3 mL) were mixed and incubated at 30 °C for 6 min, and the absorbance was measured at 734 nm against Phosphate Buffered Saline (PBS).

The antiradical capacity against the α, α-diphenyl-b-picrylhydrazyl (DPPH) radical was also measured (Brand-Williams, Cuvelier, & Berset, 1995). Liquid extracts (75 μL) were mixed with the DPPH radical working solution (3 mL). After 16 min, the decrease in absorbance (515 nm) was measured. The percentage of absorbance reduction regarding the initial value was used to calculate the inhibition percentage.

The results obtained with both methods were expressed as mmol TEAC (Trolox Equivalent Antioxidant Capacity) per gram of sample (dry basis). A calibration curve with Trolox aqueous solutions (0.1–1 mM).

2.8. Texture analysis

Raw and cooked pasta texture parameters were determined using a texturometer TA.XTplus (Stable MicroSystems, Godalming, UK) with a 5 kg load cell in a 20 °C controlled temperature room. Each test was replicated at least eight times.

The texture profile analysis (TPA) of raw pasta samples was performed in penetration mode, using a cylindrical 10 mm acrylic probe. The dough was moulded in acrylic discs (61.5 mm diameter and 18 mm height) and rested for 15 min before the probe plunged 8 mm at 1 mm/s. From the force vs. time texturograms, the parameters which discriminate the sample's texture - firmness (N), adhesiveness (N.s) and cohesiveness, were determined.

Cooked pasta texture analysis was performed after cooking pasta strands for 2 min and stopping the cooking by rinsing pasta with distilled water. The firmness (N) and adhesiveness (-N.s) properties were assessed by a cutting test following AACC method 66-50.01 (AACC, 1999a), using a blade set with guillotine (HDP/BSG). Pasta stickiness (N) after cooking was determined by compressing (9.807 N) pasta strands at 0.5 mm/s for 2 s (Fradinho, Sousa, & Raymundo, 2019). Cooked pasta extensibility was performed using a Kieffer Dough & Gluten Extensibility Rig (A/KIE), that stretched the pasta strand at 2.0 mm/s until rupture, to obtain the maximum resistance to extension (Rmax, N) and the extensibility until rupture (ERmax, mm).

2.9. Rheology measurements

Small amplitude oscillatory shear (SAOS) testing was used to monitor the viscoelastic characteristics of raw and cooked pasta samples. After pasta preparation, the dough was divided into two fractions: one portion was immediately tested, whereas another portion was cut into circular disks (30 mm diameter, 2 mm height) and cooked before testing. SAOS measurements were conducted at least in triplicate in a controlled stress rheometer (MARS III, Haake, Karlsruhe, Germany) using serrated parallel plate geometry (PP20, 20 mm diameter) to avoid the slip effect with a 2 mm gap (previously optimized). Surface geometry was covered with paraffin oil to prevent moisture loss. Samples were rested before rheological testing to allow temperature equilibration (5 min at 20 °C, previously optimized). Stress sweep tests were run at 1 Hz from 0.1 to 100 Pa to assess the linear viscoelastic region (LVR). Then, the mechanical spectra were performed through frequency sweep tests from 0.1 to 10 Hz (20 °C, 10 Pa) within the LVR previously defined for each sample.

2.10. Statistical analysis

All above trials, namely autohydrolysis extractions, pasta formulations and physicochemical analysis, were made in triplicate. Experimental data is presented as average ± standard deviation (s.d.). Significant differences between samples were assessed by Student *t*-test or one-way ANOVA followed by Tukey's HSD test at 95% confidence level ($p < 0.05$) using RStudio (version 1.1.463 – © 2009–2018 RStudio, Inc.).

3. Results and discussion

3.1. Subcritical water extraction and extract characterization

Autohydrolysis liquid extracts were characterized in terms of colour, total phenolic content and antioxidant activity evaluated using in vitro assays DPPH and ABTS (Table 1).

Results from the autohydrolysis trials with Kennebec potato peel showed that increasing temperature from 180 to 220 °C led to a darker colour of the liquid extract, expressed in terms of the reduction of L* parameter. At higher temperatures, the extraction of hydrosoluble compounds is favoured, so there is an increase of TPC in the autohydrolysis liquid extract, as also reported by several authors (e.g. Ballesteros, Ramirez, Orrego, Teixeira, & Mussatto, 2017; Plaza et al., 2010). In addition, the formation of Maillard and caramelization products at higher temperatures could contribute to this effect.

Potato peel is an excellent source of total phenolics as 50% of them are in the peel and adjoining tissues of potato. Moreover, around 65% of potato peel phenolics are in the free-form (Nara, Miyoshi, Honma, & Koga, 2006; Riciputi et al., 2018) and consequently are easily recovered

by relatively mild extraction procedures such as the eco-friendly autohydrolysis. In fact, Singh and Saldaña (2011) reported the use of subcritical water extraction method (i.e. autohydrolysis) to obtain phenolic acids from potato peel, namely caffeic and chlorogenic acids. These compounds are the predominant free-form phenolic acids in potato peel and account for 57% of total antioxidant activity (Nara et al., 2006). Based on these results, 220 °C was the AH temperature selected for apply to the other potato peel varieties.

Applying the selected AH temperature to all potato varieties, results showed that Kennebec had the highest TPC values, followed by Agria and Neiker, which had the highest antioxidant activity values measured by ABTS method. Although TPC contribution to the antioxidant activity is well established, Riciputi et al. (2018) reported the presence of different phenolic compounds in different potato peels, contributing unevenly to the antioxidant activity of these matrices.

Several authors reported a relationship between the potato peel colour characteristics and the TPC content and antioxidant capacity, with red- or purple-peel potatoes containing higher amounts of phenolic compounds compared with yellow-peel cultivars (Jeddou et al., 2018; Perla, Holm, & Jayanty, 2012; Tierno et al., 2016). In the present study, Neiker, the red peel variety showed lower TPC values than yellow-peel potatoes (Kennebec and Agria). It is worth mentioning that discarded potatoes stored at room temperature were used, which could account for the differences observed, as storage time and temperature greatly affects xanthophyll and phenolic content, as well as antioxidant capacity (Blessington et al., 2015; Galani et al., 2017).

In a previous study, the authors (Torres et al., 2020) reported that Agria potato peel also presented lower Na contents and much higher Fe and 60% more protein contents than Kennebec and Neiker varieties, which could contribute to a nutritionally rich liquid fraction than the other potato varieties.

Taking these results into account, Agria was the selected potato variety to be tested in the production of pasta product.

3.2. Pasta cooking quality

The results for the pasta quality performance upon cooking are shown in Fig. 1.

Functional ingredients introduced into the pasta formulation, especially proteins or fibre, are known to significantly influence its properties (Fradinho, Raymundo, et al., 2019; Fradique et al., 2013). Control and pasta produced with potato peel extract (PPE) present distinct water absorption and swelling power. As reported in an earlier study (Torres et al., 2020), Agria potato peel showed around 22% protein content. During autohydrolysis procedure, proteins are cleaved into water soluble peptides which are then extracted to the liquor (Castro-Puyana, Herrero, Mendiola, & Ibáñez, 2013), thus contributing for the increase of the hydration properties of pasta. Moreover, PPE

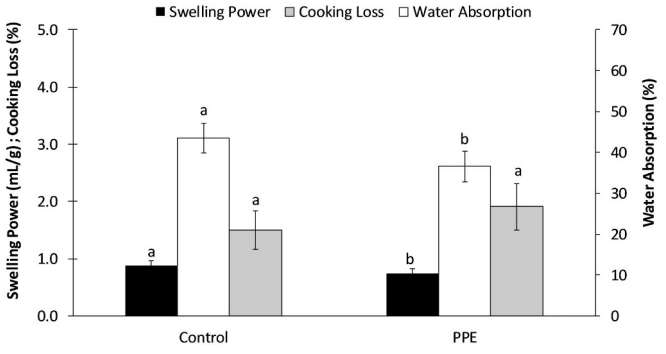


Fig. 1. Cooking quality parameters of pasta prepared with potato peel extract (PPE), and control (without extract). Data are presented as mean ± standard deviation. Different letters in the same parameter correspond to significant differences ($p < 0.05$, two sample *t*-test).

pasta showed a higher protein content than the control (Table 3) reinforcing the previous statement.

Regarding cooking loss, although the replacement of wheat flour by other non-gluten flour dilutes the strength of pasta network that holds the starch particles together, our CL results were lower than the ones reported by other authors for durum wheat pasta (e.g. Bonomi et al., 2012) stating the quality of the developed pastas. Ferreira et al. (2016) also obtained low CL values for GF pasta with potato starch, rice flour, sorghum, eggs, oil, water, therefore a much more complex formulation than the one porposed in this study. Furthermore, this simpler formula follows consumer demands for clean label sustainable foods with by-products from the food industry.

3.3. Colour stability upon cooking

Colour stability is an important attribute for the development of colourful food products. In Table 2 the results of colour parameters obtained in raw and cooked pastas are shown.

As expected, the addition of potato peel extract (PPE) changed the colour of the GF pasta, which had a pale brown colour. After thermal processing (cooking – boiling in water) both pastas revealed some change in sample colour, meaning a pigment loss (leaching) to the cooking water. All ΔE* values showed much higher values than 5, which means that the colour difference between the raw and cooked pastas is visible to the human eye (Castellar, Obón, & Fernández-López, 2006). Since the main pigments responsible for potato colour are phenolic compounds, which have hydrophilic character, this explains pigment leaching into the cooking water. In addition, colour changes during heat treatment may be associated to the phenol oxidation reaction as a result of polyphenol oxidase enzyme activity (Parveen, Threadgill, Moorby, & Winters, 2010).

3.4. Nutritional composition of pasta

In Table 3 the nutritional composition of raw and cooked pasta samples is presented.

In terms of nutritional composition, the addition of potato peel extract led to a significant increase ($p < 0.001$) of the protein and ash contents of pasta, which is maintained after cooking. Although raw PPE also showed a lower lipid content than the Control, both pastas presented similar values after cooking, meaning that free fatty acids were probably leached into the cooking water.

Upon cooking, ash content of Control remained constant, but in PPE there was a 37% loss, although still higher than the Control. This is interesting and must be due to the entrapment of potato minerals in the pasta matrix. In terms of energy value, the cooked enriched pasta aports 3% less energy value than of the Control (EV_{PPE} = 390.9 kcal/100 g; $EV_{Control}$ = 403.2 kcal/100 g).

Although potato peel presents around 22% of non-starch polysaccharides (Liang & McDonald, 2014) that could increase the dietary fibre content, these compounds are not water-soluble and therefore extracted to a great extent by autohydrolysis procedure. The insoluble fibre observed in PPE is most probably due to fibre contribution from the other pasta ingredients, namely Psyllium husk and rice (Raymundo, Fradinho, & Nunes, 2014).

Nutrition claims are assessed on the basis of the intake of the specific nutrient in the ready-to-eat food product. All cooked pastas showed < 0.5 g lipids/100 g, consequently they can withstand a fat-free claim (Regulation (EC) No. 1924/2006 (European Commission, 2006) amended by regulation (EU) no. 1047/2012) (European Commission, 2012), falling within the current trend for healthy foods.

Looking more closely at the mineral composition of cooked pastas, a significant improvement ($p < 0.001$) of major (Na, K, Mg and P) and trace minerals (Cu and I) was obtained. It is noteworthy that the increase in copper (10.4% to 39.7% RDA) and iodine (15.0% to 126.5%) contents represent > 15% of the recommended daily allowance (RDA)

Table 2
Colour parameters (L*, a*, b*, $\Delta E^*_{raw\text{-}cooked}$ and $\Delta E^*_{Control\text{-}PPE}$) of raw and cooked pastas.

	Control		PPE		$\Delta E^*_{Control\text{-}PPE}$	
	Raw	Cooked	Raw	Cooked	Raw	Cooked
L*	82.51 ± 0.40^a	66.69 ± 0.40^c	69.42 ± 0.49^b	50.65 ± 0.65^d	20.7	33.5
a*	1.08 ± 0.08^c	−0.14 ± 0.07^d	6.51 ± 0.17^b	7.58 ± 0.21^a		
b*	8.92 ± 0.21^c	5.92 ± 0.37^d	25.29 ± 0.41^a	16.82 ± 0.59^b		
$\Delta E^*_{raw\text{-}cooked}$	16.1		20.6			

Data are presented as mean ± standard deviation. Different letters in the same parameter correspond to significant differences ($p < 0.001$, one-way ANOVA, *post-hoc* Tukey test). $\Delta E^*_{raw\text{-}cooked}$ and $\Delta E^*_{Control\text{-}PPE}$ calculated using raw pasta and control pasta as reference, respectively.

according to Regulation (EC) 1169/2011 (European Commission, 2011). These values are much higher than the values reported by Orecchio et al. (2014) for commercial rice noodles and pasta, and in case of Cu it has functions on the cardiovascular integrity, lung elasticity, neovascularization, neuroendocrine function, and iron metabolism (Arredondo & Núñez, 2005), and I in regulating thyroid disease as celiac patients are more susceptible to, than non-celiacs (Torres et al., 2015).

Raw PPE pasta showed much higher Fe content than the Control, due to its content in Agria peel (485 mg/100 g) as reported by Torres et al. (2020). However, upon cooking some of this mineral is leached to the cooking water, so that Control and PPE pastas showed similar Fe contents.

These results showed that the potato peel extract addition can be used to enhance the nutritional value of GF pasta, increasing the amount of protein and minerals profile.

3.5. Phytochemical analysis in the pasta

The results of total phenolic content (TPC) and in vitro antioxidant activity (AA) of pastas, performed by DPPH and ABTS methods are summarised in Fig. 2. As pasta is consumed after cooking, the impact of thermal processing should be assessed, as it induces great changes in texture, molecule structure, nutritional content and availability (Carcea, Narducci, Turfani, & Giannini, 2017).

For both raw and cooked pastas, the TPC of potato peel enriched pasta (PPE) is around 9 times higher than of the Control. This aspect is relevant and raises the interest on the use of potato peel extracts in pasta. In addition, although a detailed sensory analysis was not carried out, in the preliminary tests of the PPE pasta, there was a very pleasant aroma and flavour (coffee-like). The presence of free-form phenolic compounds (such as chlorogenic acid and caffeic acid) has been reported in potato (e.g. Friedman et al., 2017) and already obtained using environmentally friendly extraction technologies (Alves Filho, Sousa, Rodrigues, de Brito, & Fernandes, 2020). Moreover, during potato storage at room temperature chlorogenic acid is transformed into caffeic acid (Wijngaard, Ballay, & Brunton, 2012). However, further studies on the flavours released could be performed to enlighten this matter.

3.6. Texture analysis of pasta

The addition of potato peel extract had no effect on most of the texture properties (Table 4), except for an increase in raw pasta adhesiveness. This result was lower than the observed for GF pasta enriched with *Laminaria ochroleuca* autohydrolysis extract probably due to the lower content of insoluble fibre of PPE (Fradinho, Raymundo, et al., 2019), as fibre absorbs water thus contributing to the adhesiveness of pasta (Bouasla, Wojtowicz, & Zidoune, 2017). These results are also advantageous in terms of the final product, as the consumer will find characteristics of texture and technological aptitude very similar to traditional pasta.

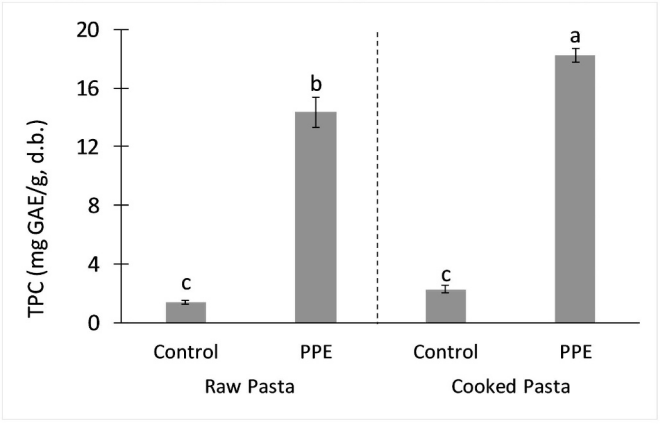
3.7. Rheology characterization of pasta samples

The results from the small amplitude dynamic rheology measurements of the raw and cooked pastas are expressed in terms of storage (G′) and loss (G″) moduli (Fig. 3).

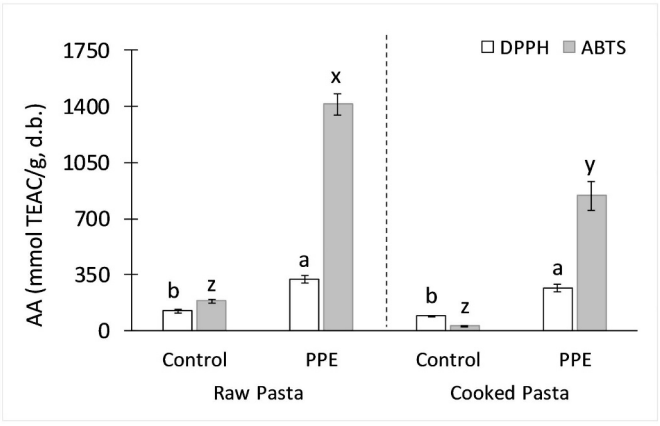
Table 3
Nutritional composition of raw and cooked pasta with potato peel extract (PPE) and Control (without extract).

			Control		PPE	
			Raw	Cooked	Raw	Cooked
	Moisture	g/100 g	50.3 ± 0.2^b	65.4 ± 1.4^a	48.9 ± 0.1^b	64.2 ± 1.2^a
Fibre	Ash	g/100 g, d.b.	0.46 ± 0.01^c	0.43 ± 0.03^c	0.87 ± 0.02^a	0.55 ± 0.02^b
	Lipids		2.17 ± 0.22^a	0.64 ± 0.18^b	0.83 ± 0.27^b	0.83 ± 0.13^b
	Protein		7.66 ± 0.15^b	7.72 ± 0.01^b	8.24 ± 0.13^a	8.46 ± 0.31^a
	Insoluble			4.83 ± 0.39^a		4.04 ± 0.11^b
	Soluble			0.94 ± 0.25^a		1.47 ± 0.50^a
	Total			6.05 ± 0.69^a		5.51 ± 0.57^a
Minerals	Na	mg/100 g, d.b	74.11 ± 2.79^{b,c}	70.00 ± 3.28^c	88.26 ± 2.34^a	82.84 ± 4.94^{a,b}
	K		325.26 ± 3.28^c	272.37 ± 4.36^d	531.86 ± 1.88^a	400.67 ± 3.26^b
	Ca		7.35 ± 1.61^a	9.92 ± 1.76^a	10.17 ± 0.54^a	9.26 ± 1.08^a
	Mg		28.26 ± 0.22^c	27.58 ± 0.48^c	36.24 ± 0.35^a	30.89 ± 0.10^b
	P		115.78 ± 2.33^b	109.54 ± 0.65^c	129.58 ± 3.05^a	118.18 ± 1.45^b
	S		109.00 ± 4.15^{a,b}	104.70 ± 1.75^b	117.36 ± 5.25^a	112.64 ± 2.91^{a,b}
	Fe		0.68 ± 0.35^b	1.16 ± 0.08^b	2.67 ± 0.42^a	1.35 ± 0.36^b
	Cu		0.27 ± 0.00^b	0.26 ± 0.14^b	0.27 ± 0.10^b	1.11 ± 0.28^a
	Zn		1.06 ± 0.04^b	1.32 ± 0.12^{a,b}	1.33 ± 0.03^{a,b}	1.65 ± 0.36^a
	Mn		0.75 ± 0.12^a	0.77 ± 0.14^a	0.76 ± 0.06^a	0.77 ± 0.04^a
	I		0.10 ± 0.00^c	0.07 ± 0.00^c	0.43 ± 0.02^b	0.53 ± 0.03^a

Data are presented as mean ± standard deviation. Different letters in the same row correspond to significant differences ($p < 0.001$, one-way ANOVA, post-hoc Tukey test and $p < 0.05$, two sample *t*-test).



a



b

Fig. 2. Total phenolic content (a) and Antioxidant Activity (b) of raw and cooked pastas: with Potato peel extract (PPE) and control (without extract). DPPH: α,α-diphenyl-b-picrylhydrazyl; ABTS: 2,2-azinobis(3-ethyl-benzothiazoline-6-sulfonate); TPC: total phenolic content; GAE: gallic acid equivalent; AA: antioxidant activity; TEAC: Trolox equivalent antioxidant capacity. Different letters in the same parameter correspond to significant differences ($p < 0.001$, one-way ANOVA, *post-hoc* Tukey test).

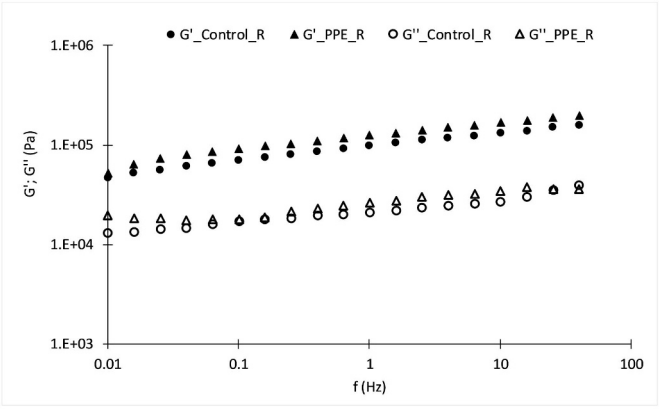
Table 4
Texture of raw and cooked pasta with potato peel extract (PPE) and Control (without extract).

		Control	PPE
Raw pasta	Firmness (N)	3.24 ± 0.54^{a}	3.26 ± 0.41^{a}
	Adhesiveness (−N.s)	0.24 ± 0.09^{a}	0.38 ± 0.10^{b}
	Cohesiveness	0.47 ± 0.02^{a}	0.45 ± 0.02^{a}
Cooked pasta	Firmness (N)	2.76 ± 0.29^{a}	2.49 ± 0.20^{a}
	Stickiness (N)	1.51 ± 0.44^{a}	1.23 ± 0.45^{a}
	Rmax (N)	0.58 ± 0.10^{a}	0.64 ± 0.08^{a}
	ERmax (mm)	4.61 ± 1.40^{a}	5.08 ± 0.93^{a}

Data are presented as mean ± standard deviation. Letters in the same row correspond to significant differences ($p < 0.05$, two sample *t*-test).

For both raw and cooked pastas the storage modulus values (G′) are higher than those of the loss modulus (G″), which reveals the more elastic nature of the structure of the studied samples.

Raw pastas showed a rheology dependent on the frequency, but upon cooking, there was a decrease in both viscoelastic moduli accompanied by an increase in G′ and G″ distance, meaning a softened matrix but with a reinforcement in the pasta structure. After thermal



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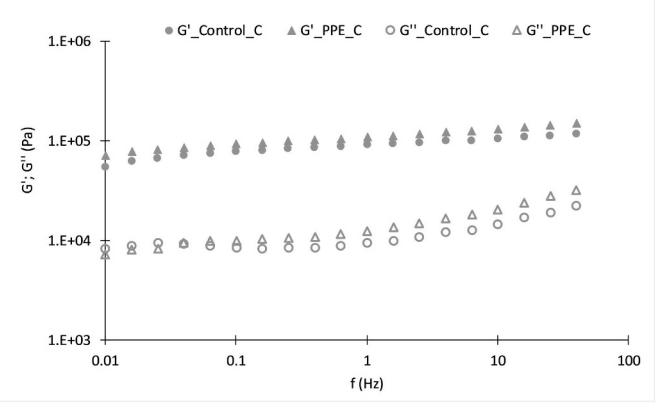

b

Fig. 3. Mechanical spectra of raw (a) and cooked (b) GF pastas: with Potato Peel Extract (PPE) and control (without extract). Closed symbols - storage modulus, G′; open symbols - loss modulus, G″.

treatment pasta also showed a less dependence of G′ with the frequency and a minimum in G″, which indicated a second degree of structuring due to the entanglement of the biomolecules that comprise the food matrix (Ferry, 1980). This behaviour is consistent with the one previously observed by the authors regarding GF pasta enriched with edible brown seaweed (Fradinho, Raymundo, et al., 2019).

4. Conclusions

Low-sized or irregular shape discarded potatoes have a great potential to be valued back into the food chain. Subcritical water extraction (220 °C) was an efficient eco-friendly technology that allowed the recovery of bioactive fractions from the potato peel. Potato peel extract revealed to be an attractive ingredient to improve the nutritional value of gluten-free pasta, increasing its mineral content, total phenolic content and antioxidant activity, without affecting the mechanical properties of the product.

Credit author statement

Patrícia Fradinho: Conceptualization, Methodology, Investigation, Formal analysis, Writing-Original draft preparation; António Oliveira: Investigation; Herminia Domínguez: Funding acquisition, Supervision, Writing- Reviewing and Editing; María Dolores Torres: Investigation, Writing- Reviewing and Editing; Isabel Sousa: Writing- Reviewing and Editing, Funding acquisition; Anabela Raymundo: Conceptualization, Supervision, Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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