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Extruded coffee parchment shows enhanced antioxidant, hypoglycaemic, and hypolipidemic properties by the release of phenolic compounds from the fibre matrix

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Dietary fibre, phenolic compounds, and functional properties of extruded coffee parchment flour were studied to evaluate its possible use of coffee parchment as ingredient rich in dietary fibre (DF) with potential antioxidant, hypoglycaemic and hypolipidemic properties in extruded products. Coffee parchment flour treated at 160–175 °C and 25% moisture feed showed higher DF (84.3%), phenolic compounds (6.5 mg GAE/g), and antioxidant capacity (32.2 mg TE/g). The extrusion process favoured the released of phenolic compounds from the fibre matrix. Phytochemicals liberated during *in vitro* simulated digestion exhibited enhanced antioxidant capacity and attenuated reactive oxygen species in intestinal cells (IEC-6). However, physicochemical and techno-functional properties were just affected by extrusion at high temperature, although extruded coffee parchment flours exhibited lower bulk density and higher swelling capacity than non-extruded ones. Extruded coffee parchment preserved glucose adsorption capacity and enhanced α -amylase *in vitro* inhibitory capacity (up to 81%). Moreover, extruded coffee parchment maintained the ability to delay glucose diffusion and exhibited improved capacity to retard starch digestion in the gastrointestinal tract. The extrusion of coffee parchment flours preserved the cholesterol-binding ability and augmented the capacity of this ingredient to bind bile salts, favouring the inhibition of pancreatic lipase by coffee parchment. These discoveries generate knowledge into the valorisation of coffee parchment as a food dietary fibre ingredient showing antioxidant, hypoglycaemic, and hypolipidemic properties enhanced by the release of phenolic compounds from the fibre matrix through the production of extruded products.

1. Introduction

Coffee production generates large amounts of wastes,¹ which represent a severe environmental problem for coffee-producing countries, then their unsafe removal could lead to contamination of water and land.^{2,3} Coffee by-products comprise more than 50% of the coffee fruit, including coffee silverskin, husk, coffee parchment, pulp, and mucilage, and spent coffee grounds that can be reused for different applications, providing them added value.⁴ The fibrous endocarp that separates and recoats both parts of the coffee seed is the by-product coffee parchment. Recently, our group has characterised coffee parchment as a new dietary fibre ingredient source of phenolics.⁵ The study revealed that coffee parchment flour could be used for developing dietary fibre-rich functional ingredients, which may help control blood sugar levels and lower cholesterol levels. Its inclusion in extruded products as snacks would be interesting since these products are widely spread in markets. Moreover, the inclusion of a fibre-rich ingredient could reduce the high glycaemic index that characterises these food products.⁶ In this regard, extrusion technology is promising for creating new snack products or breakfast cereals with higher nutritional values such as healthy dietary fibre-enriched products.⁷ Extrusion modifies

the structure of a material, texturise it and change its functional properties as a result of pressure, high temperature, and shear forces application.^{8,9} This processing may present some advantages for the food industry, such as high productivity, versatility, low cost, short processing duration, and energy savings. During extrusion, the processing parameters (temperature, pressure, screw speed, water addition, die shape) may be modified, providing different effects on product composition and properties.⁸ Then, extrusion could have positive effects on the nutritional value, such as the elimination of antinutritional factors, starch gelatinisation, reduction of lipid oxidation, and contaminating microorganisms, among others.⁹ Regarding dietary fibre (DF), extrusion processing could modify DF fraction composition and consequently DF functionality,⁶ since it is known that physiological DF effects depend on the plant cell walls, especially of their composition and structural organisation.¹⁰ The extrusion of coffee parchment may also modify phenolic compounds, as observed for coffee silverskin.¹¹ Besides, coffee parchment phenolics have been associated with the modulation of metabolic syndrome biomarkers, which could be modified by extrusion.¹² Therefore, it is necessary to evaluate the changes that extrusion produces on coffee parchment dietary fibre and phenolic compounds before including it in extruded food products.

The present work aimed to know the dietary fibre and phenolic contents, and functional properties of extruded coffee parchment flour to evaluate its possible use as a new ingredient rich in dietary fibre with potential antioxidant, antidiabetic and hypolipidemic properties in extruded products. Hence, to achieve this objective, the contents of dietary fibre and phenolic compounds, antioxidant

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capacity, physicochemical and techno-functional properties, and *in vitro* hypoglycaemic and hypolipidemic effects were assessed in extruded coffee parchment flours.

2. Material and methods

2.1. Raw material

The farm 'Las Morenitas' (Nicaragua) supplied the raw parchment from *Coffea arabica* obtained by wet processing. From the origin, raw and dried coffee parchment was sent at room temperature in sealed bags. Once received, it was processed (milling for 72 h at 250 rpm) in a ball mill (Ortoalresa- Álvarez Redondo S.A., Madrid). The flour obtained was sieved (250 µm) and stored in sealed plastic bags at -20 °C until analysis.

2.2. Extrusion processing

The extrusion of the coffee parchment flour was carried out on a laboratory-scale with a single-screw extruder (Compact E 19/25 D; Brabender, Duisburg, Germany) with the following characteristics: 19/25D screw, a 3-mm-dia cylindrical die, and a 3:1 compression ratio. The experiment was a 2-factorial design with three moisture content (15%, 20%, and 25%) and two-barrel temperature ramps (135-150 °C and 160-175 °C) (Table 1). After extrusion six extruded coffee parchment samples were obtained. Samples were milled and stored in sealed plastic bags at -20 °C until analysis. All experiments used non-extruded coffee parchment as control and the six extruded coffee parchments samples to investigate the effects of temperature and moisture during extrusion on the chemical, techno-functional and physiological properties of coffee parchment.

2.3. Dietary fibre determination

DF was determined following the AOAC method 991.43¹³ using a total dietary fibre assay kit (Megazyme, Wicklow, Ireland). Samples were subjected to consecutive enzymatic digestions with heat-stable α-amylase, protease, and amyloglucosidase to eliminate the non-dietary fibre components. After filtration, the residues corresponded to the insoluble residues, and the filtrates were precipitated with ethanol to obtain the soluble residues. Both residues were dried and represent the insoluble dietary fibre (IDF) and soluble dietary fibre (SDF), respectively, after residual ash and protein corrections. Total dietary fibre (TDF) was estimated as the sum of IDF and SDF.

Table 1. Extrusion treatment parameters (temperature and moisture) and sample code.

Sample code	Extrusion treatment	
	Temperature (°C)	Moisture (%)
Control	Non-treated	Non-treated
E135-15	135-150	15
E135-20	135-150	20
E135-25	135-150	25
E160-15	160-175	15
E160-20	160-175	20
E160-25	160-175	25

2.4. Determination of free and bound phenolics

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The free and bound phenolic extraction was effectuated according to the method described by Rebollo-Hernanz *et al.*¹⁴ slightly modified. Briefly, 0.2 g of samples were extracted using 50 mL of methanol:HCl: water (79.5: 0.5: 20). After the sonication for 30 min, the mixture was agitated 16 h at 40 °C and centrifuged at 3000g at 20 °C for 20 min, and the supernatant was decanted. The methanolic extraction was performed twice. The supernatants of both extractions were combined and evaporated to dryness under vacuum. The residue was dissolved in 10 mL methanol: HCl: water (79.5: 0.5: 20), being the free phenolic fraction (FPC).

To get the bound phenolic fraction (BPC), hexane (10 mL) was added to the pellet and discarded. An alkaline hydrolysis under nitrogen was carried with 5 mL of 2 mol L⁻¹ NaOH for 1 h at room temperature. Then the medium was adjusted to pH 2 with 2 mol L⁻¹ HCl before phenolic acids extraction, which was carried out with 5 mL of 1:1 ethyl ether and ethyl acetate and centrifuged at 3000g for 5 min. This step was repeated three times, and all solvents were collected, filtered, and evaporated to dryness. Finally, the sample reconstitution was done in methanol: water (80: 20).

For the quantification of FPC and BPC, the Folin-Ciocalteu (FC) procedure was used in a microplate. The standard used was gallic acid, and the results were expressed as gallic acid equivalents per gram sample. The sum of FPC and BPC represents the total phenolic compounds (TPC).

2.5. Overall antioxidant capacity

Direct and indirect ABTS⁺ assays were used to measure the overall antioxidant capacity.⁵ Direct ABTS⁺ (D-ABTS) was evaluated in the solid samples as follows: coffee parchment samples were diluted with cellulose (1:10) and stirred, 10 mg of the mixture were mixed with 1.7 mL of ABTS⁺ solution. Trolox (30 µL, 10-1000 mg L⁻¹) was mixed with 10 mg of cellulose and 1.67 mL of ABTS⁺ solution to prepare the calibration curve. Samples and standards were incubated for 5 min at 37 °C and centrifuged before measuring the supernatant's absorbance at 734 nm. Indirect ABTS⁺ was measured in FPC (F-ABTS) and BPC (B-ABTS) extracts, mixing the extracts or Trolox with ABTS⁺, incubating the mixture (5 min, at 37 °C), and measuring the absorbance at 734 nm. Results were expressed as µg mg⁻¹ Trolox equivalents (TE). The antioxidant capacity of the TPC fraction (T-ABTS) was calculated as the sum of F-ABTS and B-ABTS.

2.6. Release of phenolic compounds during *in vitro* digestion and evaluation of their antioxidant potential

2.6.1. Simulated *in vitro* digestion. Gastrointestinal digestion was performed to evaluate the potential release of phytochemicals from the extruded coffee parchment flours following the harmonised INFOGEST protocol.¹⁵ Supernatant from the intestinal phase were lyophilised and stored at -20 °C until further use.

2.6.2. Determination of released phenolic compounds and *in vitro* antioxidant capacity. The content of released phenolic compounds (RPC) and the subsequent released antioxidant capacity (R-ABTS) in the intestinal phase of the simulated digestion was determined in the supernatant of the intestinal phase using the Folin-Ciocalteu and the ABTS methods, respectively, as described in sections 2.4 and 2.5.

Results were expressed as mg GAE or mg TE per g of coffee parchment flour.

2.6.3. Cell culture. Rat small intestine epithelial cells (IEC-6) were kindly provided by the Bioanalytical Techniques Unit (BAT) of the Institute of Food Science Research (CIAL) (Madrid, Spain). Cells were cultured as a monolayer in Dulbecco's Modified Eagle Medium (DMEM), supplemented with 10% (v/v) heat-inactivated fetal bovine serum (FBS), 50 U/mL penicillin, 50 µg/mL streptomycin, and 1% L-glutamine, at 37 °C, and in 5% CO₂ in a humidified incubator (BINDER CB series 2010, Tuttlingen, Germany).

2.6.4. Cell viability. The intestinal cells were seeded in 96-well plates. After 24 h of incubation, cells were treated with the intestinal phase of the digestion (500 µg mL⁻¹) and incubated for further 24 h. Cell viability was measured using the CellTiter 96® Aqueous (MTS assay) (Promega Corporation, Madison, WI, USA) according to the manufacturer's instructions.¹⁶

2.6.5. Determination of intracellular reactive oxygen species (ROS). Cells (10⁴ per well) were plated on 96-well plates. After incubation for 24 h, the cells were treated with the intestinal phase of the digestion (500 µg mL⁻¹) for further 24 h. 2',7'-dichlorofluorescein diacetate (DCFDA, 12.5 µmol L⁻¹) was added to each well for 30 min. Cells were washed with PBS and co-treated for 1 h with the intestinal phase of the digestion (500 µg mL⁻¹) and 1 mmol L⁻¹ *tert*-butyl hydroperoxide (*t*-BHP). Cells were washed with PBS and the fluorescent intensity was detected using excitation and emission wavelengths of 485 and 530 nm, respectively.¹⁶ Finally, to normalise ROS values, cell viability was measured using the CellTiter 96® Aqueous (MTS assay) (Promega Corporation, Madison, WI, USA) according to the manufacturer's instructions.

2.7. Physicochemical and techno-functional properties

pH, bulk density (BD), water holding capacity (WHC), oil holding capacity (OHC), water absorption capacity (WAC), swelling capacity (SWC), emulsifying activity (EA), foaming capacity (FC) and gelation capacity (LGC, last gelation concentration), were measured according to Benitez *et al.*⁵

2.8. *In vitro* evaluation of the hypoglycaemic properties

2.8.1. Determination of glucose-adsorption capacity. The capacity of samples to adsorb glucose was analysed by mixing each sample with four concentrations (10, 50, 100, 200 mmol L⁻¹) of glucose solution (1:100 w:v).¹⁰ After the mixture incubation (6 h at 37 °C), it was centrifuged (15 min, 3500g). The quantity of glucose adsorbed onto the sample was estimated by the difference between the initial amount of glucose and the glucose available in the supernatant. Glucose was quantified with K-GLUC (Megazyme, Wicklow, Ireland) and the results were expressed as mmol glucose adsorb g⁻¹ sample.

2.8.2. Determination of *in vitro* amylase inhibition. The capacity of samples to inhibit the α-amylase activity was determined according to Chau *et al.*¹⁷ A system formed by the mixture of the sample, potato starch solution, and α-amylase (Sigma-Aldrich, MO, USA) was incubated at 37 °C for 60 min. After incubation, NaOH (0.1 mol L⁻¹,

80 mL) was added to stop the starch degradation, and the mixture was centrifuged (15 min, 3500g). The glucose content was measured in the supernatant to find out the glucose production (µmol glucose g⁻¹ sample). A control test without samples (blank) was also developed to know the maximum glucose production.

2.8.3. Determination of *in vitro* glucose diffusion retardation. The capacity of samples to retard the glucose diffusion *in vitro* was determined according to Chau *et al.*¹⁷ with slight modifications. The sample was mixed with 50 mM glucose solution (1:50 w:v). The mixture and a control test without the addition of the sample (blank) were dialysed against distilled water (80 mL) at 37 °C using a dialysis membrane (cut-off molecular weight of 12,000-14,000). The quantity of glucose in the dialysate was measured with K-GLUC (Megazyme, Wicklow, Ireland) after incubation (10-150 min). The glucose diffusion retardation index (GDRI) at the end of the incubation was calculated as follows:

$$GDRI = 100 - \frac{[\text{Glucose}] \text{ in the dialysate with fibre addition}}{[\text{Glucose}] \text{ in the dialysate of control test}} \cdot 100$$

2.8.4. Determination of *in vitro* starch digestibility retardation. The effect of the presence of the sample on the starch digestibility was analysed following the procedure described by Ou *et al.*¹⁸ slightly modified. Sample (0.2 g) was mixed with potato starch solution (10 mL, 4% p/v) and α-amylase (4 mg) (Sigma Aldrich, MO, USA). The mix was dialysed at 37 °C against distilled water (200 mL) with a dialysis membrane (cut-off molecular weight of 12,000-14,000). The dialysed glucose was measured after incubation (10-150 min), using the assay kit K-GLUC, and compared with the glucose dialysed by a system without the addition of sample (blank). The results were expressed as the concentration of glucose dialysed (µmol glucose g⁻¹ sample). GDRI was calculated as explained in section 2.8.3.

2.9. *In vitro* evaluation of the hypolipidemic properties

2.9.1. Determination of *in vitro* lipase inhibition. The inhibitory activity against pancreatic lipase of extruded samples was measured according to Benitez *et al.*⁵ Sample and pancreatic lipase solution (0.75 mg pancreatic lipase mL⁻¹ phosphate buffer) were mixed and incubated in a water bath (37 °C, 1 h) with sodium phosphate buffer (0.1 mol L⁻¹, pH 7.2) and olive oil. After incubation, the reaction was stopped placing the test tube in a boiling water bath, and the released free fatty acids were measured by titrating with NaOH (0.05 mol L⁻¹). A similar method was carried by adding bile salts to evaluate the bile salts-binding effect on lipase activity. Lipase inhibitory activity (%) was defined as the percentage of decrease in the free fatty acid production rate over the control.

2.9.2. Determination of *in vitro* cholesterol-binding capacity. The determination of the cholesterol-binding capacity of extruded samples was determined following the method described by Benitez *et al.*⁵ Briefly, diluted fresh egg yolk (1:9) and samples were mixed, and the pH was adjusted to 2.0 and 7.0. The mixtures were incubated (37 °C, 2 h) and centrifuged (800 g 15 min). The supernatant was diluted with acetic acid, mixed with *o*-phthalaldehyde and incubated to develop the colour. Absorbance was measured at 550 nm and

cholesterol content in each sample was estimated based on a standard curve.

2.9.3. Determination of *in vitro* sodium cholate binding capacity.

Sodium cholate binding capacity was determined following the method of Benitez *et al.*⁵ Briefly, a mixture of sample, NaCl solution (0.15 mol L⁻¹, pH 7.0) and sodium cholate (Sigma-Aldrich, MO, USA) was placed on the shaker at 37 °C for 1, 2, and 3 h, and centrifuged (800g, 20 min). After that, an aliquot from the supernatant or standards were mixed with H₂SO₄ (45% v/v) and furfural (0.3% v/v) and incubated (65 °C, 30 min). After cooling at room temperature, the absorbance was measured at 620 nm. Sodium cholate was used as a standard.

2.10. Statistical analysis

The statistical analysis was carried out using SPSS 24.0. Each sample was analysed in triplicate. The data were analysed using the *T*-test or by one-way analysis of variance (ANOVA) and post hoc Tukey test. Relationships between the analysed parameters were evaluated by computing Pearson linear correlation coefficients setting the level of significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$. The statistical analysis was performed by SPSS 23.0. Multivariate analyses viz. principal component analysis (PCA) and hierarchical cluster analysis were performed with XLSTAT 2020 for Microsoft Excel 2016.

3. Results and discussion

3.1. Extrusion did not modify the content of the dietary fibre from coffee parchment flour

The results of DF showed that SDF was not detected either in control or extruded samples, then, IDF was the only DF fraction present in TDF of non-extruded (control) and extruded coffee parchment flours (Table 2). Literature reported conflicting findings of the effect of extrusion on DF.¹⁹ Chemical reactions as the breakdown of polymeric compounds might happen during extrusion. However, this effect is highly conditioned to the food matrix and the parameters of the extrusion process, being reported either increases, decreases, or non-changes on DF after extrusion.⁹ In general terms, extrusion did not produce changes in TDF/IDF content of coffee parchment flour

Table 2. Effect of extrusion on the dietary fibre content of coffee parchment (g 100 g⁻¹) under processing conditions of 135-150 or 160-175 °C and 15, 20, or 25% moisture.

	IDF	SDF	TDF
Control	77.2 ± 0.2 ^b	nd	77.2 ± 0.2 ^b
E135-15	72.0 ± 1.8 ^a	nd	72.0 ± 1.8 ^a
E135-20	81.8 ± 2.5 ^{bc}	nd	81.8 ± 2.5 ^{bc}
E135-25	80.4 ± 2.0 ^{bc}	nd	80.4 ± 2.0 ^{bc}
E160-15	79.3 ± 1.0 ^{bc}	nd	79.3 ± 1.0 ^{bc}
E160-20	79.7 ± 2.6 ^{bc}	nd	79.7 ± 2.6 ^{bc}
E160-25	84.3 ± 0.4 ^c	nd	84.3 ± 0.4 ^c

Results are reported as mean ± SD ($n = 6$). Mean values within a column followed by different superscript letters are significantly different when subjected to Tukey's test ($p < 0.05$). IDF: Insoluble dietary fibre; SDF: Soluble dietary fibre; TDF: Total dietary fibre; nd: non detected.

(Table 2), being these results similar to those found in some cereals and pulses.^{9,19} However, the treatment with the 135-150 °C ramp and 15% of moisture produced a significant reduction (7%) of IDF/TDF. These losses in IDF or TDF contents after extrusion were also reported in legume-based formulations,^{9,20} and extruded corn grains.²¹ On the other hand, a significant increase (9%) was found at high temperature and high moisture (160-175 °C, 25%), corroborating the results found in Phoenix barley by Vasanthan *et al.*²² Extrusion at mild or moderate conditions seems not to change DF content significantly, but it may solubilise some of its components, producing slight losses of DF. However, at more severe extrusion conditions, DF content tends to increase. Because of coffee parchment flour composition (lack of starch) and its dietary fibre components, mainly cellulose, hemicelluloses, and lignin⁵ DF was not solubilised after extrusion, being the increase found in DF may be due to Maillard compounds formation.

3.2. Phenolic compounds were released in extruded coffee parchment flour prompting its antioxidant capacity

Extrusion affected the total content of phenolic compounds, being temperature a key parameter. The highest temperature (160-175 °C) produced significant increases in total phenolic compounds (TPC) (Figure 1A). The main fraction of phenolic compounds was free phenolics, ranging from 60 to 87% of TPC in all the studied samples. The results showed that extrusion at 160-175 °C produced increases of free phenolic compounds (FPC); these extruded samples showed 3- or 4-fold more FPC than the control. Additionally, the treatments at 160-175 °C with 25% moisture feed significantly increased bound phenolic compounds (BPC), doubling their content regarding non-extruded coffee parchment flour. However, extrusion at 135-150 °C revealed no significant changes on TPC neither FPC, but BPC exhibited decreases with 15 and 20% feed moisture. Our results followed the same tendency found in the free and bound fractions of rice after extrusion,²³ while Gong *et al.*²¹ observed increases of both phenolic fractions of cornflour. The effect of temperature on phenolic compounds may depend on the food matrix and the type of phenolic compound present in it.²⁴ Even if thermolabile phenolics may be degraded, recent studies have proved the increased of simple phenolic compounds, potentially liberated from the fibre matrix.^{25,26} The mechanical effect of extrusion could be helpful for the release of bound phenolics from the food matrix, primarily conjugated phenolics, which were covalently bound to the insoluble fibre fraction, being laid after extrusion in the free fraction as suggest recent studies.^{9,23} In coffee parchment flour, phenolic compounds might be liberated from lignin and hemicelluloses (xylans),⁵ thanks to the extended extraction effect of the screw under high temperature and pressure, contributing to the increase of TPC at 160-175 °C. The antioxidant capacity of the free- and bound-phenolics fractions was associated with the content of phenolic in them ($r = 0.980-0.992$, $p < 0.001$) (Figure 2A). Extrusion at high temperature (160-175 °C) produced a release of phenolic compounds associated with an increase of the antioxidant capacity of these fractions. Free phenolic compounds in coffee parchment are primarily chlorogenic, vanillic, and protocatechuic acids, whereas bound phenolics are comprised of *p*-coumaric acids.²⁷ Moreover, these compounds reduce oxidative stress and regulate glucose and lipid

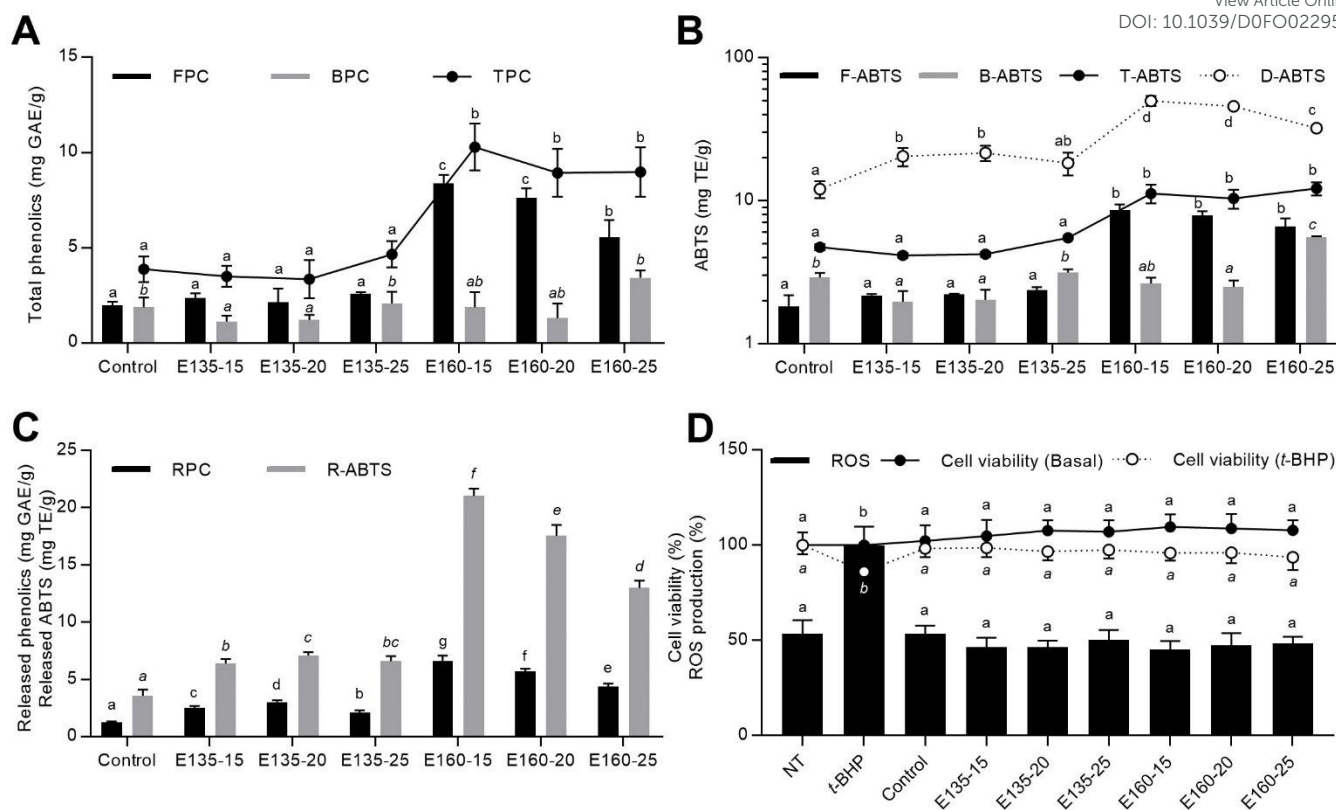


Figure 1. Effect of extrusion under processing conditions of 135-150 or 160-175 °C and 15, 20, or 25% moisture on (A) phenolic compounds (free (FPC), bound (BPC), and total (TPC)), (B) *in vitro* antioxidant capacity of coffee parchment phenolics, FPC (F-ABTS), BPC (B-ABTS), TPC (T-ABTS), and the direct antioxidant capacity of the antioxidant dietary fibre (D-ABTS), (C) released phenolic compounds (RPC) and antioxidant capacity (R-ABTS) of the intestinal phase of the digestion of extruded coffee parchment flour, (D) effect of released phytochemicals from extruded coffee parchment (500 µg mL⁻¹) upon *in vitro* simulated gastrointestinal digestion on the reactive oxygen species (ROS) production and cell viability (both basal and in oxidative states) in rat intestinal cells (IEC-6) using *t*-BHP (1 mmol L⁻¹) as an oxidant. The results are expressed as mean ± SD (*n* = 3). Bars and points with different letters significantly (*p* < 0.05) differ according to ANOVA and Tukey's multiple range test.

metabolism.²⁸ However, the measure of the antioxidant capacity of these fractions (FPC and BPC) only represents a potential measure of the released compounds in the organism. FPC could be released during the gastrointestinal digestion whereas BPC could reach the colon bound to the fibre matrix and be separated by its modification by the colonic microbiota.²⁹ The direct antioxidant capacities of extruded coffee parchment samples were greater than those of non-extruded, being the increment at 160-175 °C higher than at 135-150 °C (Figure 1B), in accordance to previous studies in different food matrices.^{9,23,30} The enhancement of antioxidant capacity could be explained by the higher antioxidant activity of the phenolic compounds released after extrusion.⁹ Phenolics (FPC and TPC) correlated with the direct antioxidant capacity (D-ABTS) ($r = 0.979$ and $r = 0.913$, $p < 0.01$, respectively) (Figure 2A). However, other compounds, apart from phenolics, participated in the antioxidant capacity of coffee parchment flours, since the direct antioxidant capacity was higher than the capacity measured in the phenolic extracts (indirect ABTS). These compounds could be different pigments (particularly, melanoidins), which exhibit antioxidant activity and might be produced by the Maillard reaction during thermal processing.^{31,32}

As observed in Figure 1C, extrusion prompted the released of phenolic compounds not only under analytical extraction conditions (FPC) but also under the mild *in vitro* simulated gastrointestinal

conditions (RPC). Extruded coffee parchment flours showed enhanced released of phenolic compounds at both temperature conditions (135 and 160 °C). RPC were significantly ($p < 0.05$) increased in comparison with the non-extruded control; 1.7 to 2.5-fold at 135 °C, and 3.6 to 5.4-fold at 160 °C. Similarly, the intestinal digestion media of extruded samples exhibited 1.8 to 2.0-fold (135 °C) and 3.6 to 5.9-fold (160 °C), respectively, higher ($p < 0.05$) *in vitro* antioxidant capacity (R-ABTS) than the non-extruded control. RPC and R-ABTS presented a highly significant correlation ($r = 0.991$, $p < 0.001$) (Figure 2A). Likewise, both RPC and T-ABTS were significantly ($p < 0.05$) associated with FPC, TPC, F-ABTS, and T-ABTS. Although *in vitro* antioxidant capacity, can serve as a first approximation to the health-promoting potential of foods, cell-based models give a more physiological insight into the capacity of samples to modulate oxidative stress. Digested coffee parchment flours did not exert cytotoxicity in intestinal cells (IEC-6) (Figure 1D). Both extruded and non-extruded samples (500 µg mL⁻¹) significantly ($p < 0.05$) inhibited *t*-BHP-triggered ROS production. No significant differences ($p > 0.05$) were observed among samples, but extrusion temperature showed a significant correlation with ROS production ($r = -0.823$, $p < 0.05$) (Figure 2A); therefore, the higher temperature is used during extrusion, the lower is ROS production in intestinal cells. Additionally, digested extruded coffee parchment flours attenuated ($p < 0.05$) the cytotoxic effects of *t*-BHP. Previous studies

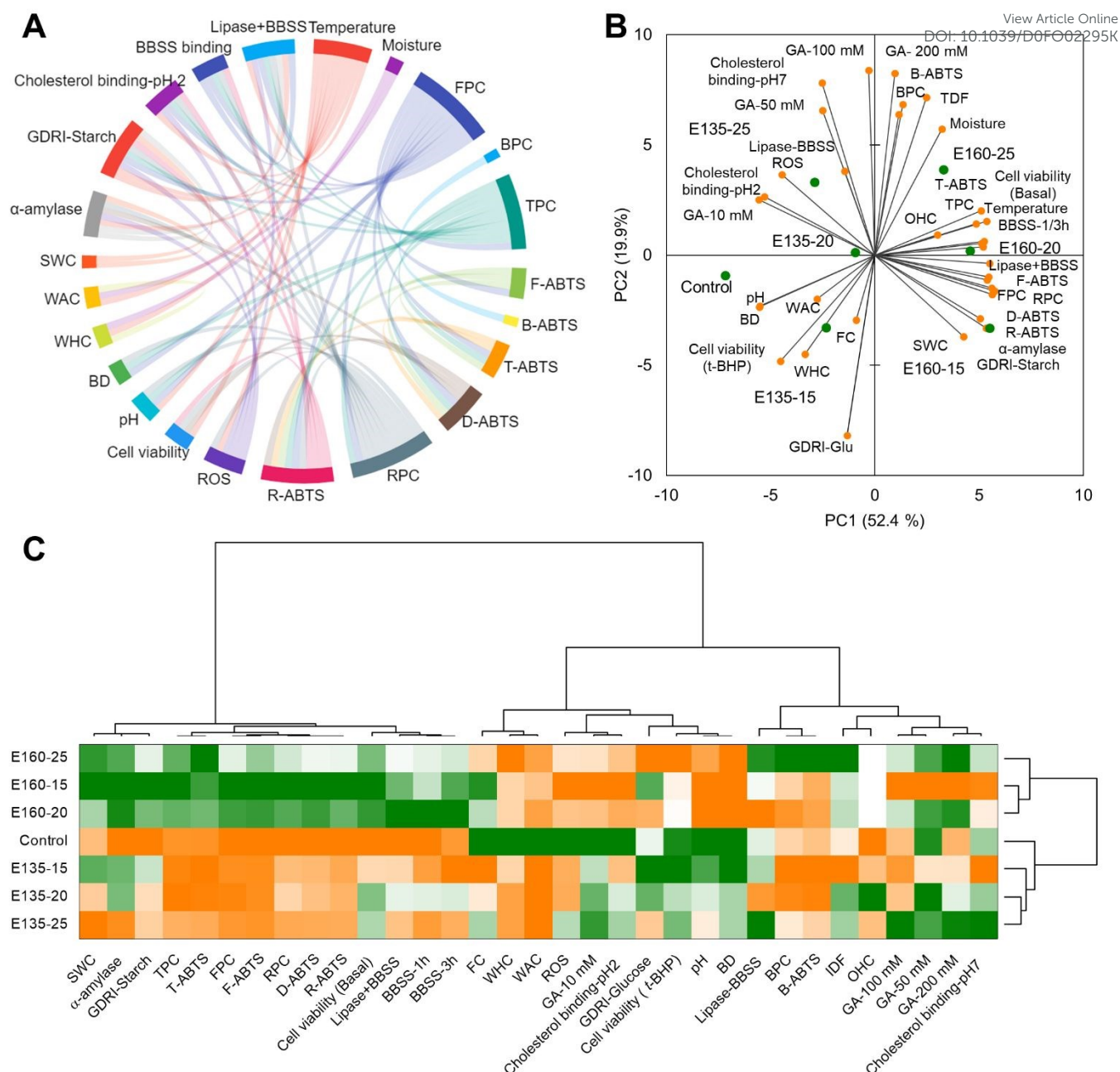


Figure 2. Chord diagram depicting the significant ($p < 0.05$) Pearson correlations ($\geq |0.75|$) among the extrusion parameters for coffee parchment, chemical composition, techno-functional properties, and *in vitro* physiological properties (A), Principal Component Analysis (PCA) (B) and agglomerative hierarchical cluster analysis coupled to heat map (from the lowest (orange) to the highest (green) value for each parameter) (C) showing the associations among the measured parameters and classifying extruded coffee parchment samples according to them.

demonstrated the effects of the aqueous soluble fraction of coffee parchment on oxidative stress.³³ Compounds extracted from coffee parchments seemed to possess a higher antioxidant capacity *in vitro* and in cell culture (HepG2 cells) than those from other coffee by-products (silverskin and husk).³³

3.3. Extrusion, primarily at high temperature, modified the physicochemical and techno-functional properties of coffee parchment flour

DF includes diverse macromolecules that exhibit a great diversity of physicochemical properties that are related to its technological properties and physiological effects. The physicochemical properties studied in extruded coffee parchment samples are shown in **Table 3**. Extrusion tended to decrease the pH of coffee parchment flours regarding control; this drop is more pronounced when the temperature and moisture feed is higher. A significant negative correlation was observed with the temperature of extrusion ($r = -0.763$, $p < 0.05$) (**Figure 2A**). These pH changes in water suspension could affect techno-functional

Table 3. Effect of extrusion on physicochemical and techno-functional properties of coffee parchment flour under processing conditions of 135–150 or 160–175 °C and 15, 20, or 25% moisture. DOI: 10.1039/D0FO02295K

	pH	BD (g mL ⁻¹)	LGC (%)	OHC (mL g ⁻¹)	WHC (mL g ⁻¹)	WAC (mL g ⁻¹)	SWC (mL g ⁻¹)	EA (%)	FC (%)
Control	4.5	0.7 ± 0.0 ^c	20	1.8 ± 0.2 ^{ab}	3.3 ± 0.2 ^b	3.7 ± 0.1 ^b	3.8 ± 0.3 ^{ab}	0	60
E135-15	4.4	0.7 ± 0.0 ^c	20	2.0 ± 0.0 ^b	2.3 ± 0.2 ^a	2.2 ± 0.2 ^a	5.7 ± 0.4 ^{cd}	0	20
E135-20	4.2	0.6 ± 0.0 ^b	20	2.6 ± 0.1 ^c	2.0 ± 0.0 ^a	2.2 ± 0.2 ^a	4.0 ± 0.5 ^{ab}	0	25
E135-25	4.1	0.6 ± 0.0 ^b	20	2.0 ± 0.2 ^b	2.0 ± 0.0 ^a	2.2 ± 0.2 ^a	3.0 ± 0.3 ^a	0	40
E160-15	3.8	0.4 ± 0.0 ^a	20	2.2 ± 0.2 ^{bc}	2.3 ± 0.2 ^a	2.6 ± 0.2 ^a	6.3 ± 0.4 ^d	0	56
E160-20	3.8	0.4 ± 0.0 ^a	20	2.2 ± 0.2 ^{bc}	2.3 ± 0.2 ^a	2.4 ± 0.0 ^a	5.2 ± 0.3 ^c	0	38
E160-25	3.9	0.4 ± 0.0 ^a	20	2.2 ± 0.2 ^{bc}	1.8 ± 0.2 ^a	2.4 ± 0.0 ^a	6.0 ± 0.3 ^d	0	20

Results are reported as mean ± SD (*n* = 3). Mean values within a column followed by different superscript letters are significantly different when subjected to Tukey's test (*p* < 0.05). BD: Bulk Density; LGC: Least Gelation Concentration; OHC: Oil Holding Capacity; WHC: Water Holding Capacity; WAC: Water absorption Capacity; SWC: Swelling Capacity; EA: Emulsifying Activity; FC: Foaming Capacity.

properties, especially those linked to the content of protein such as emulsion and foaming properties.

Bulk density (BD) is closely associated with the expansion ratio and is an important parameter in the production of formed and expanded foods.³⁴ Extrusion, in general terms, produces a BD decrease, making coffee parchment flour more porous. This reduction was sharper when the temperature was higher. However, moisture feed seems not to affect this property. BD is related to the structure of the product, especially its particle size, and its distribution, and it influences other physicochemical properties.¹⁰

Regarding gelation capacities, a useful index to predict the gelation capacity is the least gelation concentration (LGC). Thus, samples with low LGC would exhibit an adequate capacity of gelation, which is an appreciated characteristic in the production and acceptability of a large variety of foods.¹⁰ Extrusion did not affect to gelation properties of coffee parchment flour.

Concerning oil-holding capacity, extrusion did not change the capacity of coffee parchment flour to hold oil, except for the treatment at 135 °C and 20% of moisture, which slightly increased OHC of coffee parchment flour. Gong et al.²¹ neither found changes in OHC after extrusion of corn, whereas increases in OHC were found after the extrusion of soybean.³⁵ From results, extrusion seems not to modify the non-polar residues availability on the surface of coffee parchment flour. The importance of this property is related to the stabilisation of foods with high-fat percentage and emulsions, and to the capacity of samples to retain flavour and increases the mouthfeel of food due to the physical entrapment of oil.³⁶

Water absorption capacity (WAC), water holding capacity (WHC), and swelling capacity (SWC) were studied to evaluate the effect of extrusion on hydration properties (Table 3). These properties play an important role in the technological and physiological properties of a food matrix and can affect the effective integration of ingredients rich in fibre into foods.³⁷

Extruded coffee parchment flours showed lower WHC and WAC than non-extruded ones (*p* < 0.05). Significant negative correlations were observed between WHC and WAC and the extrusion temperature (*r* = −0.887 and *r* = −0.883, *p* < 0.01, respectively) and with the process feed moisture (*r* = −0.966 and *r* = −0.881, *p* < 0.01, respectively) (Figure 2A). These results would indicate that the sites for interaction with water in coffee parchment flour could have decreased with the extrusion in all studied treatments. However, studies have shown

increases in WHC and WAC after extrusion, which were related to the increase in SDF content,^{21,34,38,39} but this increase was not found in the present study.

Nevertheless, extrusion produced an increase of SWC, extruded coffee parchment flours showing similar SWC to other products.^{13,40} The SWC rise is higher for the treatment at 160–175 °C and in all moisture percentages. The increase in SWC after extrusion was also found in powders of lotus root nodes and dietary fibre of soybean residue.³⁵ Water is entrapped in the hydrophilic matrix formed by DF, especially IDF, and filled the interstices of the polysaccharides, which produce the swelling.⁴¹ In general, extruded coffee parchment flours exhibited similar hydration properties as other DF-rich products, which may indicate that these flours may be used as a functional ingredient of snacks to change their texture and viscosity or to reduce their calories. Coffee parchment flour did not have any capacity to emulsify, not even after extrusion. Lastly, foaming capacity (FC) decrease in the extrusion process.

From results, extrusion seems to make more porous products, but no significant effects were found for most techno-functional properties studied, probably due to the lack of soluble polysaccharides (SDF). However, extruded coffee parchments flours showed good swelling properties, which would provide hydration in a food matrix when they will be incorporated. Thus, these processed coffee parchments could be used as functional ingredients with the potential of calorie reduction or modification of texture and viscosity of formulated foods such as snacks or breakfast cereals. Moreover, hydration properties could also be associated with physiological effects such as antidiabetic or hypolipidemic.

3.4. In vitro hypoglycaemic activity of extruded coffee parchment

3.4.1. Extrusion preserved the glucose adsorption capacity of coffee parchment flour. Figure 3A reveals that extruded coffee parchment flours could adsorb glucose efficiently at all the glucose concentrations studied (10–200 mM). This capacity could be due to the content of DF since several DF sources have been reported to adsorb glucose.^{10,18,42} The quantity of glucose adsorb to coffee parchment flours is related to the glucose concentration found in the solution, raising as the glucose concentration increased, these glucose concentrations also affected to the extrusion impact. Thus, at low glucose concentration (10 and 50 mM), extruded samples showed a slightly lower capacity to adsorb glucose than non-

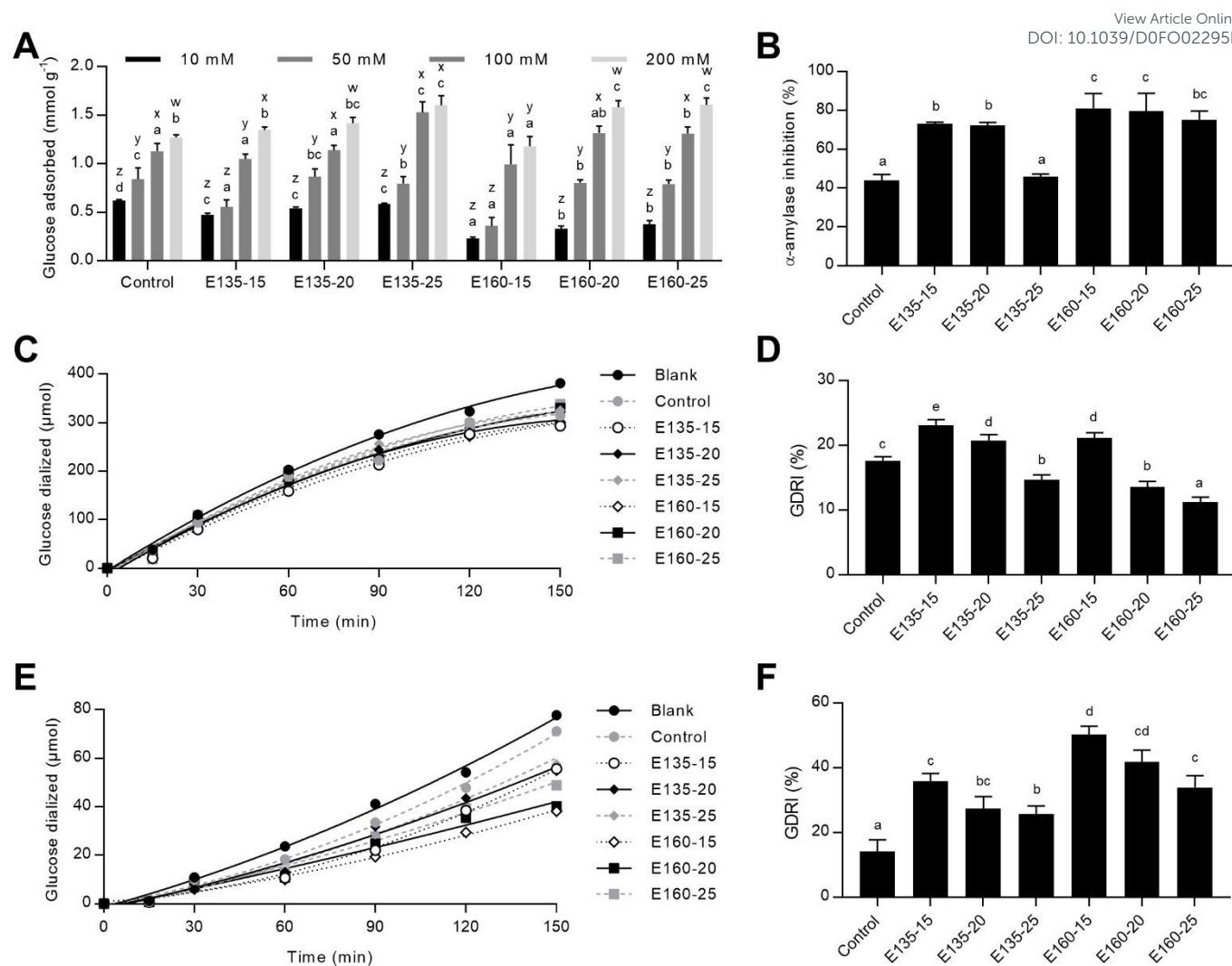


Figure 3. Impact of extrusion under processing conditions of 135-150 or 160-175 °C and 15, 20, or 25% moisture on glucose adsorption capacity (mmol g⁻¹) of coffee parchment (A), α-amylase inhibition (B), glucose diffusion kinetics (0-150 min) (C), glucose diffusion retardation index (GDRI) at the end of the incubation (150 min) (D), starch hydrolysis kinetics (0-150 min) (E), and GDRI for the glucose release from starch (F). Samples were processed at conditions of 135-150 or 160-175 °C and 15, 20, or 25% moisture. The results are expressed as mean ± SD (*n* = 3). Bars with different letters significantly (*p* < 0.05) differ according to ANOVA and Tukey's multiple range test (a,b,c: among treatments; z,y,x: among glucose concentrations).

extruded flour, as occurred when thermal treatments were applied to onion by-products.¹⁰ However, when the concentration of glucose increases in the media (100 and 200 mM), extruded samples, especially those extruded with 20 or 25% moisture feed, showed to some extent more capacity to adsorb glucose than non-extruded one. These results may indicate that extrusion could be used to produce coffee parchment flours that keeping the ability to reduce the postprandial hyperglycaemia, thanks to the reduction of the glucose availability in the intestinal lumen.⁴²

3.4.2. Extruded coffee parchment flours showed enhanced α-amylase *in vitro* inhibitory capacity. The effect of extrusion of coffee parchment flour on α-amylase activity is shown in Figure 3B regarding glucose production rate and inhibition percentage. Extruded coffee parchment reduced significantly (*p* < 0.05) the production of glucose, except for the treatment 135-15% that did not show significant differences with the blank. Extrusion at 160-175°C

increased the inhibition capacity of coffee parchment flour, ranging from 75 to 81% higher than the non-extruded sample (control, 44%). Temperature significantly correlated with the inhibition of α-amylase (*r* = 0.754, *p* < 0.05) (Figure 2A). An association between α-amylase inhibition and the direct antioxidant capacity was also shown (*r* = 0.779, *p* < 0.05). Likewise, the content of RPC significantly correlated with the inhibition of α-amylase (*r* = 0.819, *p* < 0.05), evidencing that phenolic compounds liberated from the coffee parchment fibre matrix during extrusion and released into the small intestine may be inhibiting α-amylase activity. We suggest that extrusion at high temperature might modify the coffee parchment matrix, primarily by releasing phenolics from lignin and xylans and by the potential formation of Maillard compounds, and then enhancing the antioxidant properties and herein the inhibition of α-amylase. Furthermore, α-amylase inhibition was related to SWC (*r* = 0.831, *p* < 0.05). The SWC is associated with increases in the media viscosity. In the gut, increasing viscosity reduces the enzyme mobility and then

its ability to hydrolyse starch due to lower accessibility.⁴³ Extruded coffee parchment flours might delay carbohydrate digestion by the increase of its digestion time. This fact would reduce the speed of the absorption of glucose and, consequently, blunt the postprandial increase of plasma glucose, as suggested by Ahmed and Urooj.⁴⁴

3.4.3. Extrusion maintained the ability of extruded coffee parchment flour to delay glucose diffusion. As shown in **Figure 3C, D**, the level of glucose in the dialysates increased over time from 10 to 150 min. At 10 min, all samples reduce significantly ($p < 0.05$) the glucose content in the dialysate regarding blank (glucose dialysed without sample), the non-extruded sample (control) showing the highest decrease. However, from 30 min to 120 min, in general, extruded samples produced less glucose in the dialysate than the non-extruded (control) and blank. From 150 min, there were no significant differences between extruded and non-extruded samples, all of them showing significant ($p < 0.05$) less glucose in the dialysate than blank.

In most cases, extrusion seems to improve the ability of coffee parchment flour to delay the glucose diffusion from 30 to 120 min, since the extruded samples showed higher GDRI than the one non-extruded (**Figure 3D**). This improvement in the delay of glucose diffusion after extrusion was previously reported in extruded orange pulp by Cespedes *et al.*⁴⁵ Moreover, the extrusion parameters seem to affect GDRI since extrusion treatments at 135–150 °C and moisture feed of 15 and 20 % exhibited slightly higher GDRI than those at 160–175 °C and moisture feed of 25%. Therefore, the increase in temperature and moisture seems to reduce the ability of coffee parchment flour to delay glucose diffusion.

The DF capacity to delay the glucose absorption may be related to the physical barrier that fibre particles present to glucose molecules due to the viscosity of polysaccharides and the entrapment of glucose within the matrix formed by insoluble fibre particles.^{44,45} Moreover, the capacity to adsorb glucose may also be connected to the glucose absorption retardation.¹⁸ The obtained results might indicate that extruded coffee parchment flours could delay the absorption of glucose in the gastrointestinal tract due to their capacity to adsorb glucose and postpone its diffusion.

3.4.4. Extruded coffee parchment flour exhibited improved capacity to retard starch digestion. The effects of coffee parchment extrusion on starch digestibility were evaluated by the measure of the glucose level in the dialysates comparing to the blank (**Figure 3E, F**). A glucose decrease was found from 10 min forwards owing to the presence of extruded coffee parchment flours. From 60 min, all extruded samples showed significantly lower ($p < 0.05$) glucose content in the dialysate than non-extruded ones. Therefore, the presence of coffee parchment samples in the gut might affect the starch digestibility. Moreover, extruded samples seemed to be more capable of maintaining over time the capacity to interfere with starch digestibility than non-extruded ones. Regarding GDRI during starch digestion (**Figure 3F**), extruded coffee parchment flour delayed glucose dialysis upon starch digestion 1.8 to 3.5-fold more ($p < 0.05$) than non-extruded coffee parchment flour. Temperature significantly correlated with GRDI ($r = 0.796$, $p < 0.05$) (**Figure 2A**). Likewise, associations were shown between the GDRI and FPC, TPC, F-ABTS, and D-ABTS ($r \geq 0.82$, $p < 0.05$). RPC and R-ABTS also

exhibited a significant relationship with the GDRI-Starch ($r > 0.895$, $p < 0.05$). Therefore, the release of antioxidant phenolic compounds during extrusion enhanced the starch digestion delaying ability of coffee parchment flours. The inhibition of α -amylase by the antioxidants fibres could delay the glucose diffusion due to the reduction of the glucose release from the starch.⁴² SWC and amylase inhibition were significantly associated with the GDRI ($r = 0.789$, $p < 0.05$ and $r = 0.857$, $p < 0.05$, respectively). As previously stated, the delay of starch digestibility can be associated with an increase in viscosity by reducing the enzyme mobility and decreasing starch accessibility.⁵ Several factors might be related to the capacity of extruded coffee parchment flour to decrease starch digestibility and inhibit α -amylase activity.^{18,41} Some of them are the concentration of fibre, its capacity to entrap starch, direct adsorption of α -amylase onto the fibre, the presence of inhibitors (such as phenolic compounds) in the fibre matrix, or the reduction of the enzyme accessibility to starch.

3.5. *In vitro* hypolipidemic effect of extruded coffee parchment

3.5.1. Extrusion preserved the cholesterol-binding ability of coffee parchment flour. As observed in **Figure 4A**, subjecting coffee parchment to an extrusion process did not modify its ability to quench cholesterol to a great extent. At pH 2, extrusion at high temperature (160–175 °C) diminished cholesterol-binding by 40–54%; at pH 7, coffee parchment flour cholesterol-binding capacity was reduced by 16–17% at low moisture (15%), independently of the treatment temperature. A negative association between extrusion temperature and cholesterol-binding capacity at pH 2 was observed ($r = -0.836$, $p < 0.05$) (**Figure 2A**). Thus, the temperature might be the main variable affecting extruded coffee parchment flours cholesterol absorbing properties. The pH of the media influenced the concentration of cholesterol bound to the coffee parchment matrix, higher ($p < 0.05$) absorption was shown at pH 7. Therefore, the changes produced during gastric and intestinal digestion may determine the quantity of cholesterol that may bind to coffee parchment fibers. The degree of ionisation of acidic hydroxyl on the fibre has an essential role in cholesterol. The ionisation of the hydroxyls groups of fibre diminishes in acid conditions, as in the stomach. Thus, xylans and lignin from coffee parchment might bind less cholesterol at pH 2 than at pH 7 because of the lower ionised hydroxyl group availability.⁵

3.5.2. Extrusion augmented the capacity of coffee parchment flour to bind bile salts. Extrusion positively impacted the capacity of binding bile salts of coffee parchment (**Figure 4B**). The treatment at 135–150 °C and 20% moisture and all treatments at 160–175 °C promoted (1.2 to 1.7-fold, $p < 0.05$) bile salts absorption. Time did not affect ($p > 0.05$) the bile salts binding, so they may not be liberated during intestinal digestion and, therefore, not reabsorbed. The content of phenolics (FPC and TPC) and the antioxidant capacity (F-ABTS, T-ABTS, and D-ABTS) correlated with the bile salt binding capacity ($r \geq 0.759$, $p < 0.05$) (**Figure 2A**). Similarly, RPC and R-ABTS correlated with the bile-salts binding capacity ($r \geq 0.875$, $p < 0.05$). Hence, the release of phenolic compounds or the associated release process (lignin depolymerisation) and phenolic acids liberation from xylans produced by the extrusion process may be leading to a higher

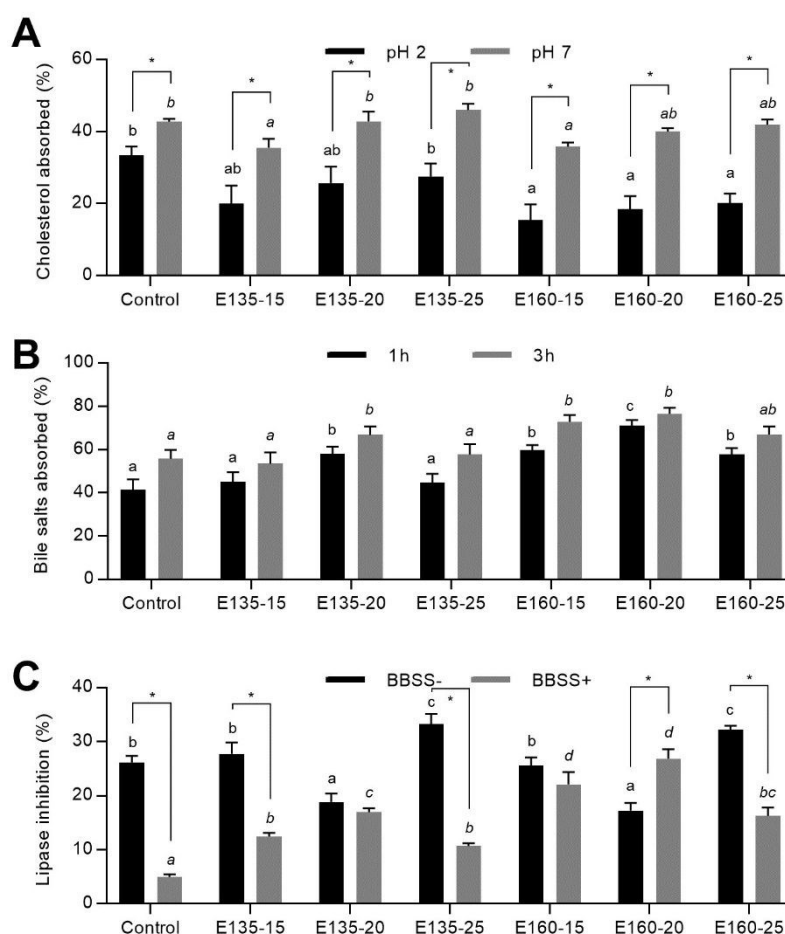


Figure 4. Effect of extrusion of coffee parchment under processing conditions of 135–150 or 160–175 °C and 15, 20, or 25% moisture on cholesterol-binding capacity (%) at pH 2 and 7 (A), bile salts binding capacity (%) at 1 and 3 h of incubation (B), and *in vitro* lipase inhibition in a model free of bile salts (BBSS–) and another containing them (BBSS+) (C). The results are expressed as mean \pm SD ($n = 3$). Bars with different letters significantly ($p < 0.05$) differ according to ANOVA and Tukey's multiple range test. Statistically significant ($p < 0.05$) differences between paired samples according to the *T*-test are represented by an asterisk (*).

capacity to bind bile salts. Phenolic compounds can bind bile acids, but also the binding sites liberated on the fibre matrix after the release of phenolics, could be related to the enhancement of the bile salts-binding capacity.⁴⁶

3.5.3. Extrusion favoured the inhibition of pancreatic lipase by coffee parchment. The inhibitory capacity of coffee parchment against pancreatic lipase was measured using two different models (Figure 4C). In the model without bile salts (BBSS–), extrusion reduced (28–34%, $p < 0.05$) lipase inhibition at 20% moisture but increased it at 25% (1.2 to 1.3-fold, $p < 0.05$). On the other hand, on the model containing bile salts (BBSS+), the ability of coffee parchment to inhibit pancreatic lipase augmented by 2.1 to 5.3-fold ($p < 0.05$). Moreover, a significant ($p < 0.05$) difference in the inhibitory capacity was shown between models. The temperature of extrusion was positively associated with coffee parchment lipase inhibitory properties ($r = 0.763$, $p < 0.05$) (Figure 2A). The changes produced by temperature might be the origin of an enhanced lipase inhibition. Lipase inhibition can be due to the formation of a coating around lipid droplets, a reduction on lipid accessibility (through enzyme mobility reduction or by lipid adsorption), an enzyme

entrapment on fibre, a destabilisation of lipidic mixed micelles by the quenching of bile salts and cholesterol, or direct enzyme inhibition by phenolic compounds or other inhibitors.⁴⁷ Lipase inhibition exhibited a significant correlation with FPC, TPC, F-ABTS, and D-ABTS ($r \geq 0.772$, $p < 0.05$) and with RPC and R-ABTS ($r \geq 0.874$, $p < 0.05$). Moreover, a significant association between lipase inhibition and bile salts-binding capacity ($r = 0.956$, $p < 0.01$). Thence, lipase inhibition could be linked to the mixed effect of bile salts binding and the direct inhibition by the released phenolic compounds in the small intestine during digestion, which could be directly inhibiting the enzyme by interacting with its catalytic site.

3.6. Extrusion enhanced the antioxidant, hypoglycaemic, and hypolipidemic properties of coffee parchment by releasing phenolic compounds from the fibre matrix

The statistical analysis enabled us to classify coffee parchment samples based on their chemical composition, antioxidant, hypoglycaemic, and hypolipidemic properties (Figure 1B, C). The first three (of six) principal components explained 85.1% of the variation.

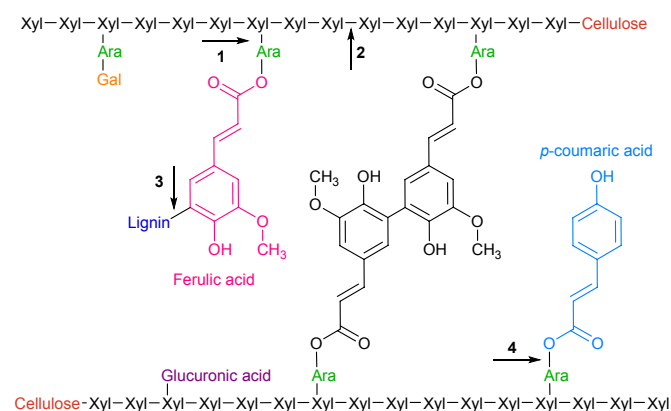


Figure 5. Proposed mechanism for the release of phenolic compounds from the fibre matrix complex of coffee parchment during the extrusion process. The cellulose-xylan-phenolics-lignin complex can be degraded under extrusion conditions in four different points (1) xylose-arabinose glycosidic linkage, 2) xylose-xylose glycosidic linkage, 3) lignin-phenolic acid ether linkage, and 4) arabinose-phenolic acid ester linkage). Ara: arabinose; Gal: galactose; Xyl: xylose.

The first principal component (PC1) explained 52.4% of the variability of the samples and was mainly composed by the temperature (3.7%), the content of free, total, and released phenolics and their antioxidant capacity (4.0 to 5.1%), and most hypoglycaemic (4.0 to 4.8%) and hypolipidemic (4.1 to 4.6%) properties. The second principal component (PC2) explained 19.9% of the variability, including extrusion feed moisture (5.1%), IDF (8.0%), BPC, and B-ABTS (6.3-7.3%), glucose absorption (6.7-10.9%), and the GDRI for glucose (10.4%). PCA and the agglomerative hierarchical cluster analysis (**Figure 1B, C**) classified sample in two groups: the first one included extruded coffee parchment samples at high temperature (160-175 °C) characterised by high phenolic content, antioxidant capacity, amylase, and lipase inhibition, and high ability to retard starch digestion; the second group comprised non-extruded coffee parchment flour and samples extruded at 135-150 °C characterised by high cholesterol-binding capacity and glucose diffusion delaying ability. These results corroborate that the extrusion of coffee parchment flour may improve the antioxidant, hypoglycaemic, and hypolipidemic properties of coffee parchment by releasing phenolic compounds from the fibre matrix.

We suggest the potential mechanism for the decomposition of the fibre matrix of coffee parchment during the extrusion process (**Figure 5**). Our results have indicated that the extrusion process can be considered as a technique favouring the release insoluble bound phenolic compounds from the fibre matrix. Previous reported indicated that bound phenolics, abundant in cell walls, are linked by hydrogen bonds (between the hydroxyl group of the phenolic acid and oxygen atoms of the glycosidic linkages of the monosaccharides residues of hemicelluloses), hydrophobic interactions, and covalent bonds such as ester bonds between phenolic acids and polysaccharides.⁴⁸ The extrusion process may lead to the hydrolysis of glycosidic linkages in hemicelluloses or celluloses and the β -O-4 ether bonds in lignin. The extrusion process might also favour the hydrolysis of the ester and/or ether bonds between phenolic compounds, lignin, and xylan.⁴⁹ Considering that main phenolic found bound the coffee parchment fibre matrix is *p*-coumaric, followed by ferulic, protocatechuic, and caffeic acids,²⁷ we may

suppose that those phenolic acids may be released from the xylan-lignin complex. Consequently, these phenolic compounds might exert physiologically beneficial properties once liberated to the digestion media (inhibition of enzymes) and absorbed in the gut (reduction of oxidative stress). Accordingly, extrusion could be considered as an appropriate process to produce foods, including coffee parchment flour, without losing its health-promoting properties but increasing its bioactive potential.

4. Conclusions

For the first time, coffee parchment flour was subjected to extrusion to evaluate its feasibility as an antioxidant ingredient to be included in extruded products. Extrusion did not modify the content of the dietary fibre from coffee parchment, but phenolic compounds were released in extruded coffee parchment flour prompting its antioxidant capacity. Thus, phenolic compounds could be liberated in the gastrointestinal tract during digestion exerting its beneficial properties. This processing, primarily at high temperature, modified the physicochemical and techno-functional properties of coffee parchment. The *in vitro* hypoglycaemic and hypolipidemic properties of extruded coffee parchment flour were improved. Our findings brought about new insights into the sustainable use of coffee parchment flour as a food ingredient rich in dietary fibre and with enhanced antioxidant, hypoglycaemic and hypolipidemic properties due to the release of phenolic compounds. A promising application for this new ingredient could be its incorporation into snack products obtained by extrusion. Suggestions to conclude this research are future studies on the effect of the addition of coffee parchment on the sensory quality of new extruded-snacks and their *in vivo* health-promoting effects, which are expected to be implemented and commercialised.

Conflicts of interest

There are no conflicts to declare.

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