Reducing the glycemic index of short dough biscuits by using apple pomace as a functional ingredient

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Abstract: The present research aimed at enriching short dough biscuits with apple pomace to evaluate the effect on glycemic index. Apple pomace was dehydrated and milled to a powder, which was characterized for soluble and insoluble dietary fiber, and for phenolic content. Apple pomace was used to partially replace wheat flour (10 and 20% w/w) in biscuits, which were characterized for their sensory properties and submitted to in vitro digestion to predict the glycemic index. Results indicated that the apple pomace contained impressive amounts of dietary fiber (nearly 40%), mainly represented by insoluble fiber (more than 25%). Apple pomace led to a significant reduction in the expected glycemic index of reformulated biscuits. The conventional biscuit presented a glycemic index of 70 and was thus classified as high glycemic index food. Substituting wheat flour by 10 and 20% with apple pomace reduced biscuit glycemic index to 65 and 60 respectively, thus ranking the product within the intermediate glycemic index foods.

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Dear Editor,

I would like to submit the manuscript entitled “Reducing the glycemic index of short dough biscuits by using apple pomace as a functional ingredient” by Marilisa Alongi, Sofia Melchior, Monica Anese for consideration for publication in LWT - Food Science and Technology.

The manuscript reports on the formulation of short dough biscuits with reduced glycemic index by partially replacing wheat flour with apple pomace. Reusing apple pomace, which is a by-product of apple juice processing, within food formulation would concomitantly satisfy the need for dietary strategies to manage type 2 diabetes and for the valorization of food discards.

Best regards
Monica Anese

Highlights

Partially replacing wheat flour with apple pomace reduced biscuits glycemic index

Glycemic index decreased from 70 to 65 and 61 upon 10 and 20% wheat flour replacement

Industrially obtained apple pomace behaved analogously to the lab prepared one

Reducing the glycemic index of short dough biscuits by using apple pomace as a functional ingredient

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Abstract

The present research aimed at enriching short dough biscuits with apple pomace to evaluate the effect on glycemic index. Apple pomace was dehydrated and milled to a powder, which was characterized for soluble and insoluble dietary fiber, and for phenolic content. Apple pomace was used to partially replace wheat flour (10 and 20% w/w) in biscuits, which were characterized for their sensory properties and submitted to *in vitro* digestion to predict the glycemic index. Results indicated that the apple pomace contained impressive amounts of dietary fiber (nearly 40%), mainly represented by insoluble fiber (more than 25%). Apple pomace led to a significant reduction in the expected glycemic index of reformulated biscuits. The conventional biscuit presented a glycemic index of 70 and was thus classified as high glycemic index food. Substituting wheat flour by 10 and 20% with apple pomace reduced biscuit glycemic index to 65 and 60 respectively, thus ranking the product within the intermediate glycemic index foods.

Keywords: type 2 diabetes; formulation; apple pomace; by-product, short dough biscuits

1. Introduction

During the last century dietary habits have considerably changed, leading to an excessive consumption of highly refined sugars and high-calorie-density foods. Such dietary change, together with sedentary lifestyle, has been correlated with the increasing incidence of chronic metabolic diseases. Among these, one of the most alarming is type 2 diabetes, which is expected to become the 7th death cause by 2030 worldwide (WHO, 2003). As type 2 diabetes is characterized by chronic hyperglycemia, dietary changes have been suggested to limit its occurrence (American Diabetes Association, 2004; WHO, 2003). Several foods have demonstrated antidiabetic properties, due to the presence of bioactive compounds, which mainly act by modulating digestive enzyme activity and intestinal transit rate, resulting in a low glycemic index. Phenolic compounds have been reported to inhibit α-amylase and α-glucosidase, thus slowing down carbohydrates digestion and glucose absorption (Kwon, Apostolidis, & Shetty, 2008; Ríos, Francini, & Schinella, 2015). The latter is also affected by dietary fiber that increases matrix viscosity and modifies gastrointestinal transit, resulting in a reduced accessibility of starch to enzymatic hydrolysis (Brennan, 2005; Juvonen *et al*., 2009).

A promising formulation approach for type 2 diabetes management is thus using functional ingredients rich in phenolics and dietary fiber, which are typically contained in fruit and vegetables (Stamataki *et al*., 2016; Laguna, Salvador, Sanz, & Fiszman, 2011; Plazzotta, Calligaris, & Manzocco, 2018). These are often processed, generating tons of discards that are generally disposed of or used to produce energy, but that are still rich in bioactives (Rodríguez, Jiménez, Fernández-Bolaños, Guillén, & Heredia, 2006). Biochemical processing or chemical extraction have also been proposed to recover such value-added compounds, but they are costly and require an efficient management framework. Reusing processing discards, upon only negligible changes, might be a promising approach to obtain foods designed to address specific functions.

It is noteworthy that each year 10 million tons apple pomace are obtained from apple juice production worldwide. Apple pomace consists of flesh, peels, seeds, and stalks and contains a great amount of high value-added compounds, mainly represented by dietary fiber (Wolfe & Liu, 2003). The aim of the present study was to elucidate whether a partial replacement of wheat flour by apple pomace in a short dough biscuit decreased its glycemic index.

2. Materials and methods

2.1.Apparatus and chemicals

The following apparatuses were used to carry out the experimental trials: vacuum oven (Bicasa, Milano, Italy), oven (Electrolux Professional, Pordenone, Italy), mill (Retsch, Hann, Germania), kneading machine (Kenwood, Milano, Italy), food laminating machine (Imperia & Monferrina, Roma, Italy), centrifuge (Brea, California, USA), spectrophotometer (Shimadzu Corporation, Kyoto, Japan), micro-centrifuge (Hittich, Tuttlingen, Germania), tristimulus colorimeter (Minolta, Osaka, Japan), texture analyzer (Instron LTD, High Wycombe, UK), freeze-drier (Edwards Alto Vuoto, Milano, Italia). α-Amylase from *Bacillus* sp., porcine pepsin, porcine pancreatin, porcine bile extract, amyloglucosidase from *A. niger*, L-(+)-arabinose, D-(-)-fructose, D-(+)-glucose, sucrose, HCl, NaOH, $CaCl_2(H_2O)_2$, Na_2CO_3, $NaHCO_3$, NaCl, KCl, KH_2PO_4, $MgCl_2(H_2O)_6$, $(NH_4)_2CO_3$ and total dietary fiber assay kit were purchased form Sigma Aldrich (Milano, Italy). Folin-Ciocâlteau’s reagent, acetonitrile and ethanol 98% (v/v) were purchased form Carlo Erba Reagents (Milano, Italy). Deionized water (System advantage A10®, Millipore S.A.S, Molsheim, France) was used.

2.2.Apple pomace preparation

Apple pomace, consisting of peel, pulp, seeds, and stem, was recovered during the extraction of *Golden delicious* apple juice at laboratory or industrial scale. It was immediately dehydrated by using a vacuum oven (75 °C and 0.1 MPa) or a freeze-drier. Oven-dried and freeze-dried apple pomaces obtained at laboratory scale were named AP_{od} and AP_{fd}, respectively, while apple pomace recovered at industrial scale was oven-dried and named AP_{ind}. Samples were milled (particle size < 200 µm) and stored at 20 °C and 5% RH.

2.3.Short dough biscuits preparation

Biscuit without (Control) or with 10% (R10) or 20% (R20) apple pomace were prepared (Table 1). The ingredients were mixed by a kneading machine and the dough was left to stand for 30 min at 4 °C. The dough was rolled out into a 2-mm layer and 50 mm diameter discs were obtained. Samples were baked at 140 °C for 15 min, removed from the oven, cooled to room temperature and sealed under vacuum in flexible polylaminate pouches for storage in dark conditions until analysis.

2.4.In vitro digestion

In vitro digestion was carried out according to the protocol proposed by Minekus *et al.* (2014), with minor changes. The simulated salivary (SSF), gastric (SGF) and intestinal (SIF) fluids were prepared and stored at 4 °C. The fluids were preheated to 37 °C just before *in vitro* digestion. Biscuits were milled for 30 s and 1 g sample was placed into a 50-mL falcon tube with 0.1 g L-(+)-arabinose as internal standard. The oral phase was started by adding 6 µL of $CaCl_2(H_2O)_2$ (0.3 M), 194 µL of water and 800 µL of a 6.4 mg/mL α-amylase solution, prepared in SSF and providing 75 U/mL activity in the final mixture. The sample was maintained at 37 °C under stirring for 2 min. At the end of the oral phase, the pH was adjusted to 3.0 with 40 µL HCl (1 M). Subsequently, 140 µL water and 1.82 mL of a 0.31 mg/mL pepsin solution, prepared in SGF and providing 2,000 U/mL activity in the final mixture, were added to start the gastric phase. The mix was stirred at 37 °C for 2 h. At the end of the gastric phase, the pH was adjusted to 7.0 with 30 µL NaOH (1 M). The intestinal phase was initiated by adding 8 µL $CaCl_2(H_2O)_2$ (0.3 M), 262 µL of water, 3.2 mL of 22.15 mg/mL pancreatin solution, prepared in SIF and providing 100 U/mL activity in the final mixture, and 0.5 mL of 160 mM bile extract prepared in SIF. The mix was stirred at 37 °C for 2 h. A secondary intestinal phase was conducted by adding 0.1 mL amyloglucosidase to the digestion mix, which was maintained under stirring at 37 °C for 2 h. After 20, 60, 90 and 120 min from the beginning of the secondary intestinal phase, a sample was collected and the *in vitro* digestion was stopped by adding ethanol 98% (1:4 v/v). Samples were centrifuged at 10,000 g for 5 min at 4 °C. The supernatant was collected and analyzed for sugar content, as described in paragraph 2.5.3. White bread (62.3% flour, 34.6% water, 1.2% salt, 1.0% bakery yeast, 0.9% sugar, w/w) was also *in vitro* digested and analyzed for sugar content.

2.4.1. AUC and glycemic index computation

Glucose release during the secondary digestion phase was plotted against time and the area under curve (AUC) was obtained (Matthews *et al*., 1990). The glycemic index was computed (Wolever, Jenkins, Jenkins, & Josse, 1991) as reported in Equation 1.

$$GI = \frac{AUC_s}{AUC_r} \times 100 \qquad (1)$$

where AUC_s and AUC_r represent respectively the area under curve of glucose release relevant to the sample or to the reference food, i.e. white bread (Brouns *et al*., 2005).

2.5.Solids and dietary fiber

Total solids were determined by gravimetric method (AOAC, 1995). Soluble and insoluble dietary fiber was analyzed by using the total dietary fiber assay kit (AOAC International, Method 985.29, 1997), and expressed on dry weight basis.

2.6.Total phenolic content

Five g apple pomace were extracted in 75 mL water, for 60 min at 100 °C. The mixture was cooled down and centrifuged at 7,000 g for 10 min at 4 °C to collect the apple pomace extract. Total phenol content was determined according to Singleton, Orthofer, and Lamuela-Raventos (1999). Briefly, 100 µL apple pomace extract was added to 900 µL water, 5 mL Folin-Ciocâlteau's reagent and 3.5 mL of Na_2CO_3 (150 g/L). The mixture was incubated for 2 h at 25 °C and absorbance was measured at 765 nm. Total phenolic content was calculated as $mg_{\text{gallic acid equivalent (GAE)}}/g_{\text{dry weight}}$.

2.7.Sugars

The apple pomace extract and the supernatant collected after *in vitro* digestion of biscuits and bread were analyzed according to Englyst *et al.* (1999). Sugar were separated by an HPLC (Agilent 1260 Infinity Quaternary LC, Agilent Technologies, Germany) equipped with an auto-injector (1260 ALS), a chromatographic column (Amino 100 A, 5 µm, 250 mm, 4.6 mm, SephaChrom, Rho, Italy), a temperature control system (1260 TCC) and a quaternary pump (1260 Quat Pump), generating a flow rate of 1 mL/min. The mobile phase was represented by water and acetonitrile (30:70, v/v) and the injection volume was 20 µL. Monosaccharides were detected by a refractive index detector (1260 RID). A solution of D-(+)-glucose (0.05 g/mL), D-(-)-fructose (0.025 g/mL) and sucrose (0.05 g/mL) was diluted to 1:5, 1:10, 1:20 (v/v), added with L-(+)-arabinose (0.01 g/mL) as internal standard and used for calibration.

2.8.Water-holding capacity (WHC) and oil-adsorption capacity (OAC)

Apple pomace WHC was determined according to Sudha, Baskaran, and Leelavathi (2007), with slight modifications. Aliquots of 0.05 g of apple pomace were mixed with 1 mL water in a microcentrifuge tube, centrifuged at 13,000 *g* for 30 min, and decanted the excess water. The sample was weighed, and WHC was expressed as $g_{\text{water}}/g_{\text{dry weight}}$. OAC was similarly determined, by using sunflower oil instead of water. OAC was expressed as $g_{\text{oil}}/g_{\text{dry weight}}$.

2.9.Color

Color was analyzed using a tristimulus colorimeter and expressed in CIE units as L* (lightness/darkness), a* (redness/greenness) and b* (yellowness/blueness) (Clydesdale, 1978).

2.10. Firmness and thickness

Dough firmness was determined by penetrating 3 mm a 20-mm-thick dough layer at 100 mm/min with a 6.2 mm cylindrical probe attached to a 0.1 kN unit. Biscuit firmness was determined by compressing 10 g sample at 150 mm/min speed with a ten-blade Kramer shear cell attached to a 5.0 kN unit. Force-distance curves were recorded (Automated Materials Testing System, Version 5, Series IX, Instron Ltd.), and firmness was taken as the maximum force required to compress samples. The thickness of biscuits before and after baking was also measured.

2.11. Sensory analysis

Thirty panelists were involved in the sensory evaluation under laboratory conditions. A 7-point hedonic scale (1 low intensity, 7 high intensity) was used and panelists were instructed to compare the sample (R10 and R20) to the reference (control), which was attributed 4 points. Seven parameters representative of quality attributes (Popov-Raljić, Mastilović, Laličić-Petronijević, Kevrešan, & Demin, 2013), i.e. texture, crispiness, sweetness, sourness, shortbread flavor, baked flavor and fruit flavor, were considered.

2.12. Statistical analysis

Data were reported as mean ± standard deviation of at least three measurements on two replicated samples. Analysis of variance (ANOVA) was performed with significance level set to $p<0.05$; the Bartlett procedure was used to test the homogeneity of variances, using R software, version 3.4.3 (The R Foundation for Statistical Computing, 2018).

3. Results and discussion

3.1.Physical and chemical properties of apple pomace

Results of chemical and physical analyses of AP_{od} and AP_{fd} are reported in Table 2. Both AP_{od} and AP_{fd} presented a low moisture content, accounting for nearly 5%. Dry matter was mainly represented by TDF (37%), consisting of SDF and IDF with a ratio 1:3, in agreement with the literature (Carson, Collins, & Penfield, 1994; Rana, Gupta, Rana, & Bhushan, 2015). TDF was determined only in the AP_{od} sample as drying is not expected to affect its content. TDF was in the same range as reported by other authors, i.e. 30 to 50% of total solids (Yan & Kerr, 2013; Shea *et al.*, 2015; Sudha *et al.*, 2007). The wide span of fiber concentration described in the literature can be attributed to the high matrix variability. Additionally, since apple pomace residues from apple juice processing, its composition is affected not only by the extrinsic (e.g. climatic conditions) and intrinsic (e.g. variety, ripeness degree) factors influencing apple growth, but also by storage conditions and dehydration techniques (Gullón, Falqué, Alonso, & Parajó, 2007). The latter, and in particular thermal processing, are expected to induce phenolics degradation (Lu and Foo, 1997). TPC actually accounted for 1.06 $mg_{GAE}/g_{dry\ weight}$ in AP_{od}, while a higher content was detected in AP_{fd} (2.0 ± 0.1 $mg_{GAE}/g_{dry\ weight}$), in agreement with literature findings (Wolfe, Wu, & Liu, 2003). Despite low-temperature dehydration technologies could prevent phenolics degradation, they require higher costs when compared to high-temperature methods, which represent thus a more feasible option for food industries aiming at valorizing processing by-products.

Consistently with literature data, fructose was the major component of AP_{od} and AP_{fd} sugars, accounting for 66 and 64% of total sugar content, respectively, while glucose and sucrose accounted for 25 and 24, and 9 and 12%, respectively (Gullón *et al.*, 2007).

Color parameters indicated a golden yellow hue of both samples. A lower lightness was observed in AP_{od}, as compared to AP_{fd}, which resulted also less reddish. As observed by other authors (Martins, Jongen, & Van Boekel, 2001; Yan & Kerr, 2013), exposure to high temperature during drying may induce color changes of apple pomace due to the Maillard reaction.

The hydration properties of apple pomace fell in the same range reported by other authors, namely 1.6-8.4 $g_{water}/g_{dry\ weight}$ for WHC and 1.2-2.0 $g_{oil}/g_{dry\ weight}$ for OAC (Figuerola *et al*., 2005; Sudha *et al*., 2007; Rana *et al*., 2015). Apple pomace presented a 2.5-fold higher WHC than wheat flour (Joshi, Liu, & Sathe, 2015). The good hydration properties of apple pomace could be attributed to its higher content in soluble dietary fiber (more than 10%), when compared to wheat flour, in which SDF generally accounts for less than 5% (Taneyo, Di Silvestro, Dinelli, & Gianotti, 2017).

3.2.Effect of apple pomace use on biscuit physical, chemical and sensory properties

Apple pomace was used to partially substitute wheat flour in biscuits. Only AP_{od} was used, due to the higher feasibility of conventional dehydration techniques. The physical and chemical properties of biscuits prepared by replacing wheat flour with AP_{od} at 10 and 20% levels are presented in Table 3. As the concentration of AP_{od} increased, the thickness of biscuits decreased, when compared to the conventionally formulated biscuit (i.e. control), in agreement with the literature (Sudha *et al.*, 2007). The limited volumetric increase can be attributed to the strong WHC of apple fiber (Table 2) which in turn might be related to changes in dough firmness (Chen, Rubenthaler, Leung, & Baranowski, 1988). The latter significantly increased when wheat flour was partially replaced by apple pomace, corresponding to 1.1 ± 0.1, 1.6 ± 0.1 and 1.7 ± 0.1 N for control, R10 and R20 respectively, potentially impinging volume increase during baking. In fact, firmness of R10 and R20 biscuits (Table 3) resulted lower ($p<0.05$) than that of the control sample. Similarly, Matejová, Fikselová, Čurlej, and Czako (2016) observed a reduction in biscuit firmness when wheat flour was replaced with apple, buckwheat and grape pomaces. Such a difference is not expected to rely on moisture, which was comparable for all biscuits (i.e. 3.5 ± 0.6%), but could depend on other interactions occurring within the matrix. The partial removal of wheat flour reduced gluten content, thus limiting gluten development during mixing and resulting in softer biscuits (Devisetti, Ravi, & Bhattacharya, 2015).

As expected, the control sample only contained sucrose, while the concentration of fructose, which was the major AP_{od} sugar (Table 2), increased as as apple pomace content increased. Even if glucose was found in AP_{od}, it was not detected in reformulated biscuits, due to its depletion upon Maillard reaction occurring during baking (Martins *et al*., 2001).

The lightness of AP_{od}-containing biscuits significantly decreased when compared to the control, while a* and b* concomitantly increased, indicating a more pronounced browning of biscuits containing apple pomace, due to the presence of glucose and fructose, which represent reactants of the Maillard reaction. The latter is well known to induce browning in baked foods, caused by the development of melanoidins and other Maillard reaction products. These compounds also affect the sensory properties of baked foods, leading to characteristic flavors (Martins et al., 2001). To understand if and to what extent reformulation intervention affected the perception of biscuit sensory properties, some representative descriptors (Popov-Raljić *et al*., 2013) were evaluated based on a hedonic scale and results are reported in Fig. 1. Wheat flour replacement by AP_{od} did not affect the perception of most descriptors, such as firmness, crispiness, sweetness, sourness, and shortbread flavor (Fig. 1). On the contrary, the baked and fruit flavors were differently perceived in biscuits containing 10 and 20% APP_{od}. Both reformulated biscuits presented significantly higher scores ($p<0.05$) for the baked flavor when compared to the control, probably due to the faster evolution of the Maillard reaction in AP_{od}-containing biscuits (Martins *et al*., 2001). The fruit flavor resulted significantly more intense ($p<0.05$) in biscuits containing the highest amount of AP_{od} (20%), while the lower concentration (10%) did not affect its perception when compared to control. An improvement in the sensory profile of bakery goods obtained with a partial substitution of wheat flour with apple pomace were observed by other authors (De Toledo, Nunes, Da Silva, Spoto, & Canniatti-Brazaca, 2017), who described also an improvement of nutritional properties in bread and biscuits.

3.3. Effect of apple pomace use on biscuit glycemic index

Conventional and AP_{od}-containing biscuits were *in vitro* digested to assess the effect of reformulation on the predicted glycemic index. Fig. 2 shows glucose concentration during the second intestinal phase of *in vitro* digestion.

Glucose concentration increased during *in vitro* digestion for all samples, presenting a sharper growth during the first 20 min of the second intestinal phase. As expected, the maximum glucose concentration, accounting for 155 $mg/g_{dry\ weight}$ after 90 min, was recorded in white bread. Glucose concentration in control biscuits increased up to 120 $mg/g_{dry\ weight}$ after 120 min. On the contrary, the maximum glucose concentration recorded for AP_{od}-containing biscuits corresponded to 98 and 97 $mg/g_{dry\ weight}$ for R10 and R20, respectively, after 20 min.

Glucose concentration data collected during the second intestinal phase of *in vitro* digestion were used to estimate the glycemic index of control, R10, and R20. The conventional biscuit (control) presented a glycemic index of 70.4 ± 0.2 and was thus classified as high glycemic index food. Substituting flour by 10 (R10) and 20 (R20) percent significantly ($p<0.05$) reduced biscuit glycemic index to 65.7 ± 1.8 and 60.8 ± 1.9 respectively, thus ranking the product within the intermediate glycemic index foods (American Diabetes Association, 2004).

The reduction in the glycemic index, which resulted significant in biscuits with the highest AP_{od} content, can be attributed to the considerable TDF content of this by-product (Table 1). Total dietary fiber is well known to contribute to glycemic index reduction by several mechanisms. Soluble dietary fiber can increase matrix viscosity at gastrointestinal level, contributing to the formation of a gel. The latter can envelop starch grains, protecting them from the amylolytic activity of digestive enzymes and thus impinging the release of free glucose, resulting in a reduced glycemic response (Brennan, 2005; Juvonen *et al*., 2009). Despite insoluble dietary fiber does not directly influence postprandial glucose excursions, it plays a part in affecting the glycemic response, as it was demonstrated to affect gut transit time and was associated with a significant reduction of type 2 diabetes risk (Weickert & Pfeiffer, 2018; Wilfart, Montagne, Simmins, Noblet,

& Van Milgen, 2007). Since AP_{od} presented a higher WHC than that reported in the literature for wheat flour, this by-product could entrap the water contained in the dough. Consequently, during biscuit baking, starch gelatinization would be partially prevented, inducing the retention of a high concentration of native starch. The latter can also be defined as resistant starch, since it is inaccessible to digestive enzymes due to the persistence of crystalline form (Miao, Jiang, Cui, Zhang, & Jin, 2015). In other words, resistant starch cannot be hydrolyzed in the gastrointestinal tract to release free glucose, thus not contributing to the glycemic response (Englyst *et al.*, 1999).

Despite sugar content increased from 46 (control) to 60 (R10) and 65% (R20), a significant reduction in the glycemic index estimate was found when apple pomace was used to partially replace wheat flour. A further reduction in the glycemic index could thus be pursued by balancing the amount of sucrose used in biscuit formulation with sugars deriving from apple pomace.

3.4.Characterization and use of apple pomace deriving from industrial processing

Since AP_{od} effectively reduced the glycemic index of biscuits, further trials were carried out to understand if apple pomace deriving from industrial processing (AP_{ind}) presented performances similar to those of AP_{od} obtained at laboratory scale. Table 4 reports the major functional properties of AP_{ind}, potentially affecting biscuit formulation.

Despite TDF content of apple pomace obtained from the industrial process resulted higher than that found in apple pomace produced at laboratory scale (Table 2), it was in the same magnitude span and presented the same SDF:IDF ratio (i.e. 1:3) as reported by other authors (Carson *et al.*, 1994; Rana *et al.*, 2015). Analogously, WHC and OAC values corresponded to those relevant to apple pomace. Since AP_{ind} presented functional properties similar to what observed for AP_{od} (Tables 2 and 4), this by-product was used to replace by 20% the flour in biscuit (Table 1). The glycemic index was then assessed and resulted analogous (62.0) to that observed for biscuits containing the same amount of AP_{od}. Based on these results, it can be stated that the by-product of apple juice production obtained at the industrial level could be exploited as an ingredient to reduce the glycemic index of biscuits.

4. Conclusion

Results acquired in the present study demonstrated the efficacy of a formulation approach aimed to reduce food glycemic index by reusing vegetables discards. This would concomitantly satisfy the need for dietary strategies to manage type 2 diabetes and for the valorization of food by-products. Reusing them within food formulation would not only reduce food discards, thus limiting the food production environmental impact, but could also deliver nutritional advantages. To this regard, further research would be required to characterize bioactives contained in processing by-products, as well as to minimize the effect of further processing, required to convert by-products into ingredients, on bioactives content. Nonetheless, the functionality of new formulations should be validated *in vivo*.

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Captions for figures

Fig. 1. Sensory scores attributed to biscuits containing 0 (control), 10 (R10) and 20 (R20) percent apple pomace (AP_{od}) on flour basis.

Fig. 2. Glucose concentration as a function of time during the second intestinal phase, relevant to biscuits containing 0 (control), 10 (R10) and 20 (R20) percent of apple pomace (AP_{od}) on flour basis.

Table 1
Composition of biscuit dough samples. Ingredients are listed according to the adding sequence. Wheat flour was substituted by 0 (control), 10 (R10) and 20 (R20) percent (w/w) of apple pomace on flour basis.

Ingredients (% w/w)	Control	R10	R20
Egg	20.7	20.7	20.7
Sucrose	17.2	17.2	17.2
Sunflower oil	8.6	8.6	8.6
Wheat flour	51.6	46.4	41.3
Apple pomace	-	5.2	10.3
NaCl	0.2	0.2	0.2
Baking powder	1.7	1.7	1.7

Table 2

Dry matter, total (TDF), soluble (SDF) and insoluble (IDF) dietary fiber, fructose, glucose and sucrose, total phenolic (TPC), color, water holding (WHC) and oil absorbing (OAC) capacity of oven-dried (AP_{od}) or freeze-dried (AP_{fd}) apple pomace powders.

		AP_{od}	AP_{fd}
Dry matter (%)		94.6 ± 0.1^b	95.1 ± 0.1^a
TDF (%)		36.6 ± 0.2	n.d.
	SDF	9.2 ± 0.2	n.d.
	IDF	27.4 ± 0.1	n.d.
Sugar (mg/$g_{dry\ weight}$)	Fructose	115.6 ± 0.5^a	116.6 ± 0.5^a
	Glucose	44.4 ± 0.2^a	42.2 ± 0.1^b
	Sucrose	14.9 ± 0.2^b	21.1 ± 0.2^a
TPC (mg_{GAE}/$g_{dry\ weight}$)		1.1 ± 0.1^b	2.0 ± 0.1^a
Color	L*	77.8 ± 0.5^b	84.9 ± 0.4^a
	a*	2.6 ± 0.2^a	-0.7 ± 0.3^b
	b*	22.5 ± 0.4^b	25.1 ± 0.4^a
Hydration properties	WHC (g_{water}/$g_{dry\ weight}$)	4.7 ± 0.2^a	3.3 ± 0.1^b
	OAC (g_{oil}/$g_{dry\ weight}$)	1.0 ± 0.6^a	1.0 ± 0.1^a

n.d.: not determined

Table 3

Sugar content, thickness, firmness, and color of biscuits containing 0 (Control), 10 (R10) and 20 (R20) percent apple pomace powder (AP_{od}) on flour basis.

Sample	Thickness (mm)	Firmness (kN)	Sugar (mg/g_{ss})			Color		
			Fructose	Glucose	Sucrose	L*	a*	b*
Control	4.4±0.5^{a}	1.2±0.1^{a}	n.d.	n.d.	46.3±1.3^{b}	86.1±0.5^{a}	5.0±0.4^{b}	16.2±0.8^{b}
R10	2.8±0.2^{b}	0.8±0.0^{c}	8.9±0.1^{b}	n.d.	51.5±1.4^{ab}	73.3±0.4^{b}	10.8±0.3^{a}	22.1±0.6^{a}
20	2.1±0.1^{c}	1.0±0.1^{b}	11.5±0.0^{a}	n.d.	52.3±0.1^{a}	72.4±0.3^{c}	11.3±0.1^{a}	21.6±0.4^{a}

n.d.: not detected.

Table 4

Total (TDF), soluble (SDF) and insoluble dietary fiber (IDF), water holding (WHC) and oil absorbing capacity (OAC) of apple pomace powder deriving from industrial processing (AP_{ind}).

TDF (%)		47.2 ± 0.1
	SDF (%)	12.7 ± 0.1
	IDF (%)	34.5 ± 0.1
Hydration properties	WHC ($g_{water}/g_{dry\ weight}$)	5.0 ± 0.4
	OAC ($g_{oil}/g_{dry\ weight}$)	1.2 ± 0.1

Figure

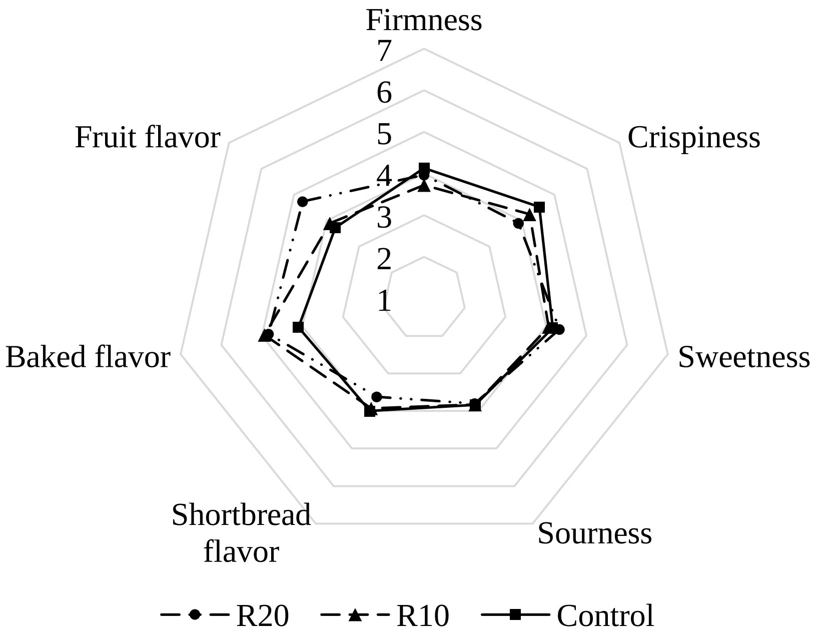
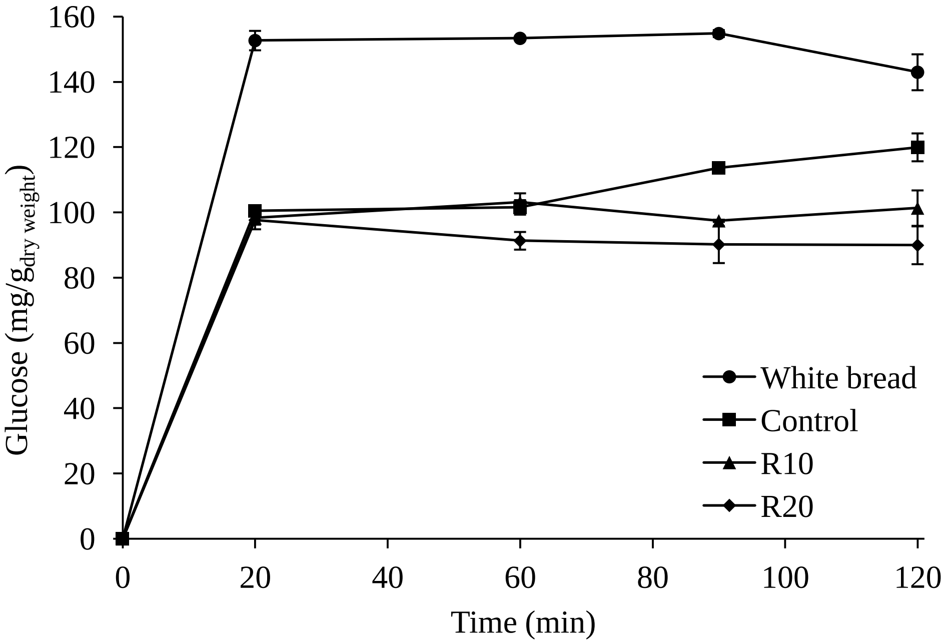

Firmness
Crispiness
Sweetness
Sourness
Shortbread flavor
Baked flavor
Fruit flavor
7
6
5
4
3
2
1
R20
R10
Control

Fig. 1.

Figure



160
140
120
100
80
60
40
20
0
Glucose (mg/g$_{\text{dry weight}}$)
0
20
40
60
80
100
120
Time (min)
White bread
Control
R10
R20

Fig. 2.