



Original article

Shortbread cookies reformulation by raspberry powder enrichment: functional and sensory aspects

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Summary The consumer is looking for foods that can satisfy the need to combine nutrition and well-being, not only balanced in their composition but also endowed with properties that can improve, or at least maintain, a good state of health. The study aims to enrich the short-crust pastry with raspberry powder, as a base for breakfast biscuits, increasing its antioxidant properties. Optimising the extent of integration with raspberry powder helped avoid interference with the cross-linking process of the gluten mesh. The reformulation of shortbread cookies was compared with that of non-enriched biscuits to define chemical composition, antioxidant potential, and sensory profile. A consumer test helped to evaluate the acceptability of the new formulations. The results indicate that the integration with the optimal identified percentage of raspberry powder, by-products of juice production, represents an excellent matrix to increase the health properties of shortbread cookies, improving functionality and sensory acceptability.

Keywords Antioxidant properties, bakery products, raspberry powder, sensory attributes, consumer adequacy, shortbread cookies.

Introduction

A critical study on breakfast eating habits involving 18 177 subjects (53.2% women) aged ≥ 35 years, with an average age of 54.6 ± 11.5 years, revealed that in Italy, breakfast is undoubtedly 'Sweet'. The most consumed foods, in addition to drinks such as coffee (93.9%), milk (67.7%), and tea (33.4%), are rusks (87.9%); there is a large consumption of biscuits (42.9%), croissants (38%), and, to a lesser extent, breakfast cereals (17%) (Di Giuseppe *et al.*, 2012).

Furthermore, in the investigation conducted by Vanelli *et al.* (2005) on the breakfast habits of 747 boys and 455 girls, divided into two homogeneous age groups (6–10 and 11–14 years), it was found that 78% of school-age children habitually consumed breakfast. Breakfast products (76%) and milk (71%) were the most frequently consumed foods. According to Nielsen (2023), the market for home breakfast products in Italy is valued at over 8 billion euros, with packaged shortcrust pastry biscuits alone worth around 829 million euros. These cookies are a staple in an Italian breakfast and are made from essential ingredients: flour, eggs, butter, and sugar. These ingredients can be adjusted to create different textures and flavours.

Flour forms the foundation of shortbread and can be substituted with alternatives like whole wheat or gluten-free flour (such as rice or almond flour). Eggs provide structure and richness, and changing the ratio of egg yolks to egg whites can alter the consistency. Butter adds flavour and tenderness, with the amount used affecting the biscuit's richness.

Meanwhile, sugar sweetens the biscuits and affects their texture – white sugar can make them crispier, brown sugar can add a caramel-like flavour, and powdered sugar can make them softer. From a nutritional standpoint, these biscuits are high in carbohydrates, primarily from flour and sugar, providing a quick burst of energy ideal for starting the day. The fats from butter and eggs contribute to a sensation of fullness, while flour and eggs provide small amounts of protein. However, traditional shortbread cookies have a nutritional imbalance due to their high sugar and fat content and low protein and fibre content, which can lead to rapid spikes in blood sugar levels and only support high energy needs (Jenkins *et al.*, 2021).

As with other products, consumer demand is shifting towards healthier options, from organic to gluten-free products with lower calories intake than fat or protein. This trend reveals that consumers are increasingly aware of the role diet plays in maintaining optimal health and preventing specific conditions

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related to dietary imbalances, such as obesity, hypertension, diabetes, osteoporosis, and cardiovascular diseases.

However, short-crust pastry doughs can vary greatly depending on the desired final product. The type of flour can be replaced or integrated, for example, by using wheat flour or flour from other cereals, including gluten-free ones for foods suitable for coeliacs. This allows to optimise the biological value of proteins.

This awareness has recently led to numerous efforts to reformulate shortbread cookies to achieve a better nutritional profile by reducing sugar and fat and incorporating functional ingredients such as antioxidants, minerals, and fibre (Luo *et al.*, 2019).

In a recent study, for example, the integration of potato pulp into the mixture was evaluated to create a line of functional products with a higher dietary fibre content. The results showed that potato pulp not only serves as an excellent flour substitute but also provides a valuable use for this by-product of the starch industry, thus reducing its environmental impact (Boruckowska *et al.*, 2020).

The study of Nuzzo *et al.* (2022) involves the use of pomegranate peel powder (PPP). Researchers have demonstrated that adding PPP to biscuits significantly enhances their antioxidant properties due to its rich phenolic compound content. Biscuits containing 3% and 5% PPP were found to offer substantial health benefits, particularly in supporting the therapy of chronic inflammatory diseases of the intestinal tract (Nuzzo *et al.*, 2022).

Another interesting research focus is on Rapeseed Press Cake (RPC). This by-product of rapeseed oil production is rich in phenolic compounds and fats, contributing to the antioxidant capacity of the biscuits. However, while higher RPC content improves antioxidant properties, it also affects the sensory qualities of the biscuits, such as taste and texture (Szydłowska-Czerniak *et al.*, 2021).

Moreover, artichoke by-products have been used to enrich biscuits with fibre-rich powders extracted from these by-products (FRPA). The study showed that biscuits made with FRPA displayed high antioxidant activity and stability during storage. Compared to biscuits made with pea fibre, those enriched with FRPA had a higher content of bioavailable polyphenols, making them a superior option for fibre enrichment in bakery products (José *et al.*, 2023). Lastly, Honrado *et al.*, 2024, demonstrated that using fish by-products, enrich biscuits from a nutritional perspective.

These are just some of the studies that propose using food processing by-products to create healthier biscuits while promoting sustainability by reducing food waste.

Many of the biscuit reformulation proposals aim to increase the antioxidant power, considering that it

now seems demonstrated by numerous medical research that oxidative stress, such as those caused by a hectic lifestyle, exposure to chemical substances, smog, poor physical activity, and poor nutrition, can profoundly interfere with human metabolic activities, from normal cellular functioning and enzymatic activities, up to aberrations in gene expression with the appearance of numerous degenerative diseases, leading to causes of death in recent decades (Sharifi-Rad *et al.*, 2020).

Taking antioxidant phytochemicals can help prevent many diseases. However, it has also been shown that one antioxidant cannot be replaced by another, having the same effect in vitro (Chen *et al.*, 2018). Furthermore, the intake of antioxidants from food or a supplement seems to have different effects, just as there are other beneficial effects of many substances in vitro and in vivo (Fernández-García *et al.*, 2012). Some studies have shown that fruits and vegetables contain bioactive substances capable of activating antioxidant mechanisms in the body thanks to other substances, which are not necessarily antioxidants but are responsible for a synergistic effect (Kurutas, 2016). Enriching foods with fragments of fruit and vegetables rich in bioactive substances can lead to the intake of compounds with a high antioxidant effect.

The objective of the present study was to manufacture functional breakfast biscuits enriched in antioxidant adding raspberry powder as a natural source and investigate their quality in terms of sensory evaluation, consumer acceptability, and antioxidant activity through chemical and sensory profiles.

Materials and methods

Chemicals

2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic) acid (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), Folin-Ciocalteu phenol reagent, Gallic acid, and Methanol (analytical grade) for extraction was purchased from Merck (© 2024 Merck KGaA, Darmstadt, Germany).

Raspberry powder preparation

The solid residue (seeds and skins) from the extraction of juice from raspberries (*Rubus idaeus* L. cv. Heritage) was oven-dried (electric oven Combi plus 8x2) at 48 ± 2 °C for about 16 h until reaching a moisture content of $10.87 \pm 0.032\%$. The dried residue was then ground in a wood mill (Komo Fidibus XL Plus) and sieved through a stainless-steel sieve with 300 µm gauge mesh (Sieve stainless steel, M.R.S. Scientific Ltd United Kingdom) (De Santis *et al.*, 2022).

Biscuits preparation

Five biscuit formulations were developed by substituting the wheat flour with raspberry powder at 0% (CS), 1.16% (RS1), 2.32% (RS2), 3.48% (RS3), and 4.64% (RS4) (Table 1). The formulations aimed to assess the impact of raspberry powder on the nutritional content and quality of the biscuits. The biscuits were prepared according to a recipe described in the AACC method, with slight modifications (AACC International, 2000). Crystalline sugar (22.98%) was mixed with butter (22.98%) for 8 min to produce a creamy batter. The dry ingredients, including salt (0.19%) and wheat flour, were added to the creamy batter to reach a final weight of 100 g.

Whole eggs (7.89%) were then added to form the dough. The dough was carefully divided to obtain pieces weighing 4.29 ± 0.6 g each. These pieces were then rounded and shaped into biscuits (2.5 ± 0.2 cm diameter with $1 \text{ cm} \pm 0.1$ thickness) before baking at 180°C for 20 min in a fan oven. The biscuits were packaged in polyethylene bags and stored at room temperature (25°C) until analysis. The workflow for biscuit development is shown in Figure S1.

Proximate analysis

Moisture and ash were determined according to the American Association of Cereal Chemists (AACC) method (AACC, 2009) on uncooked and cooked biscuits. Samples were analysed in triplicate. The thickness, length, and diameter of biscuits were measured using a calliper.

Antioxidant and polyphenols analysis

Raspberry powder, raw and cooked biscuits extraction

For raspberry powder extraction, 0.2 g of powder was mixed with 10 mL of 80% methanol and treated with an ultrasonic bath (model DU32, Argo Lab, Italy) on ice for 15 min (working frequency of 40 kHz and

maximum input power of 120 W). Raw and cooked biscuits were frozen with liquid nitrogen and ground in a blender. 1 g of sample mixed 10 mL of 80% methanol was left in ultrasonic bath (model DU32, Argo Lab, Italy) on ice for 15 min at 40 kHz. The extracts were then centrifuged (NEYA 16R, Remi Elektrotechnik LTD, India) at 1400 rpm for 20 min (De Santis *et al.*, 2022). The supernatant was recovered and kept at -20°C until use. Extraction was performed in triplicate for each sample.

Total phenolic content (TPC)

On the extracted samples, TPC was analysed following the Folin–Ciocalteu method (Bacchetti *et al.*, 2020), with minor modifications. Briefly, 1580 μL of deionised distilled water were mixed with 20 μL of the sample and 100 μL of Folin reagent, and the mixture was left in the dark at room temperature for 5 min. Then, 300 μL of 20% sodium carbonate (Na_2CO_3) solution was added, and the mixture was incubated at 40°C for 30 min before reading the absorbance at 765 nm using a UV–VIS spectrophotometer (Lambda 850+, Perkin Elmer, USA). Phenolic concentration was calculated by interpolation with a calibration curve (20–300 mg/mL) of gallic acid (R_2 0.9996), and the results were expressed as mg gallic acid equivalents on fresh weight basis (mg GAE/g fw). Determination was carried out in triplicate on the three different extracts.

Antioxidant activity

Antioxidant activity was investigated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) methods.

The capacity to scavenge DPPH free radicals was measured following the method described by Xiao *et al.* (2020). 20 μL of samples at different concentrations (diluted 1:2) were mixed with 100 μL of 0.2 mM DPPH solution and 80 μL of Tris–HCl buffer, then incubated in the dark at room temperature for 30 min. The absorbance was read against a blank at 517 nm

Table 1 Ingredients (g/100 g) of the conventional biscuits (CS) and biscuits raspberry powder enriched (RS)

g/100 g	Conventional Short-crust (CS)	Raspberry Short-Crust (RS1)	Raspberry Short-Crust (RS2)	Raspberry Short-Crust (RS3)	Raspberry Short-Crust (RS4)
Butter	22.98	22.98	22.98	22.98	22.98
Wheat flour	45.96	44.80	43.64	42.48	41.32
Raspberry flour	0.00	1.16	2.32	3.48	4.64
Salt	0.19	0.19	0.19	0.19	0.19
Egg	7.89	7.89	7.89	7.89	7.89
Sugar	22.98	22.98	22.98	22.98	22.98
Total (g)	100	100	100	100	100
% Wheat flour replacement	0	2.59	5.32	8.19	11.23

using UV–Vis spectrometer (Perkin Elmer Lambda 850+). The radical scavenging activity (RSA%) was calculated using the following equation:
$$RSA_{DPPH}(\%) = \frac{(ABS_{DPPH} - ABS_{SAMPLE})}{ABS_{DPPH}} \times 100.$$

The ABTS scavenging activity was evaluated according to the procedure described by Re *et al.* (1999), with modifications as follows. A solution of 7 mM ABTS was prepared and mixed with potassium persulphate $K_2S_2O_8$ (140 mM) (final concentration 2.45 mM), then left to react for 14 h at room temperature in the dark. The ABTS solution was diluted with ethanol to an absorbance of 0.7 ± 0.02 at 734 nm before use. 20 μ L of the sample was added to 980 μ L of the ABTS solution and left to react for 5 min. After the incubation time, the solution was read at 734 nm. The radical scavenging activity (RSA%) was calculated using the following equation:
$$RSA_{ABTS}(\%) = \frac{(ABS_{ABTS} - ABS_{SAMPLE})}{ABS_{ABTS}} \times 100.$$
 Determination of antioxidant activities was carried out in triplicate on the three different extracts.

Sensory profile

The sensorial test was performed by a panel of eight expert sensory judges (three males and five females, aged between 26 and 35 years) recruited on university department staff.

The evaluation form used for the test was divided into two parts. The upper one collected personal data and indications on the procedure during the trial. The second part reported the attributes helpful in describing the sensory profile, which the judges had to evaluate if perceived in the product for intensity on a 5-point scale.

The descriptors inserted in the left part of the form were selected by same tasters trained on the experimental samples during the selection phase before the trial.

The list of descriptors was chosen using the consensus method (ISO 13299, 2016) to establish the sensory profiles of the products (Table 2).

The judges were given three single units of each of the five samples. The shape of the pastry was approximately oval, with a length of about 4.5 ± 0.4 cm and a width of 2.5 ± 0.6 cm, with a thickness of about 1 ± 0.2 cm, and coded with three random numbers, the evaluation form, and a glass with medium mineralised water. The judge's effect is always assumed to be random. An ANOVA model is applied to each descriptor to check whether the scores assigned by the judges are significantly different.

Consumer sensory evaluation

Thirty-three consumers (fifteen males and eighteen females, with an average age of 24 ± 6 years), were recruited from students and employments of Tuscia

Table 2 Definition of each descriptor inserted in the profile sheet

Cohesion	The degree to which the components of a substance hold together, indicating its internal bonding and consistency
Colour Intensity	The depth or strength of colour observed in a product, often indicating the concentration or presence of specific ingredients or cooking processes
Fruity	A sensory attribute describing a taste or aroma reminiscent of fresh fruit, often associated with sweetness and acidity
Caramel	A sensory characteristic associated with the taste or aroma of caramelised sugar, often described as sweet, rich, and slightly burnt
Buttery	A sensory descriptor for a smooth, creamy texture, or taste reminiscent of butter, often associated with richness and a slightly salty or sweet flavour
Friability	The tendency of a substance to crumble or break into small pieces easily, indicating a dry and brittle texture
Hardness	The firmness or resistance to deformation of a substance when pressure is applied, indicating how hard or soft it is
Sweet	A primary taste sensation characterised by the presence of sugar or similar compounds, providing a sugary flavour
Bitter	A primary taste sensation that is sharp and often unpleasant, typically associated with alkaloids and certain plant compounds
Sour	A primary taste sensation characterised by acidity, often associated with the presence of acids in foods like citrus fruits and vinegar
Persistence	The length of time a taste or aroma remains noticeable after the substance has been consumed or removed from the mouth

University, Viterbo, Italy, all consumed breakfast biscuits more than once a week.

Three units of each type of biscuit, were served on white plates, labelled with three-digit random numbers, slightly sparkling mineral water was used to neutralise the mouth during the test. The hedonic test (ISO 11136, 2020) was performed in the single booths of a sensory evaluation laboratory (ISO 8589, 2007), under artificial red light and at a controlled temperature (22 ± 2 °C), ensuring good air exchange between a group of tasters and the next.

Consumers were asked to evaluate the overall sensory preference of the cookies samples, using a five-point hedonic scale (5 = like extremely, 1 = dislike extremely).

Data analysis

All chemical-analytical tests performed on the samples were replicated at least three times.

All the analytical data were subjected to Bartlett and Shapiro–Wilk test to verify normality and

homogeneity of the variances. Once these pre-requisites were verified, one-way ANOVA and Tuckey test for multiple comparison at $P \leq 0.05$ were performed separately for cooked and uncooked biscuits. The XL-Stat version 1.3, 2020 (Lumivero, Denver, CO, USA) and GraphPad Prism (© 2024 GraphPad Software, Boston, MA, USA) were used to characterise the products, and determine descriptors discriminating power in the sensorial study and to carry out a non-parametric Kruskal–Wallis test on the consumer test data.

Results and discussion

Composition and antioxidant capacity of raspberry powder

The dried raspberry powder used for biscuit enrichment in this study was the same as used in De Santis *et al.* (2022). It exhibited a moisture content of approximately $10.87 \pm 0.03\%$ and an ash content of 1.66 ± 0.01 g per 100 g of powder. TPC was 2511.76 ± 162 mg GAE, and the antioxidant capacities, as measured by the ABTS and DPPH assays, were 2440 ± 196 and 1770 ± 121 μ M TE per 100 g of powder, respectively. These findings confirm the powder's effectiveness as a source of antioxidants. It is noteworthy that these values can vary even within the same plant species due to factors such as cultivation methods and pedoclimatic conditions. In our study, the results were consistent with those reported in previous research on similar matrices (Ćetojević-Simin *et al.*, 2015; Gao *et al.*, 2018; Veljković *et al.*, 2019; Wu *et al.*, 2019).

Physicochemical characteristics of biscuits samples

Uncooked conventional biscuits (CS) and raspberry powder-enriched biscuits (RS1, RS2, and RS3) have a water content ranging from 10.55% to 11.31% and a dry matter content between 88.99% and 89.45% (Table 3). As expected, after cooking, the dry matter increased and the moisture content decreased. Specifically, cooked biscuits as a dry matter ranging between 97.77% and 96.55% and water content between 3.45% and 2.23%. Considering that none of these values showed statistically significant differences ($P < 0.05$), the biscuits enriched with raspberry powder, exhibiting dry matter and moisture content similar to that of the control cooked biscuits, represent a suitable formulation for production and consumer acceptance due to their preserved texture. Hence, enriching biscuits with functional ingredients can be challenging, particularly considering their moisture content, which should ranges from 2% to 5% (Charissou *et al.*, 2007), and the desired crumbly texture that needs to be maintained (Chevallier *et al.*, 2000; Ameer *et al.*, 2006).

Table 3 Dry matter (%), moisture content (%), and ash (%) in raw conventional biscuits (CS) and raw biscuits raspberry powder enriched (RS1, RS2, RS3, and RS4), and in cooked conventional biscuits (B_CS) and cooked biscuits raspberry powder enriched (B_RS1, B_RS2, B_RS3, and B_RS4)

	Dry matter (%)	Moisture (%)	Ash (%)
Raw short-crust pastry			
CS	89.45 $\pm$ 0.20 ns	10.55 $\pm$ 0.20 ns	0.33 $\pm$ 0.06 ns
RS1	88.99 $\pm$ 0.31 ns	11.00 $\pm$ 0.31 ns	0.30 $\pm$ 0.06 ns
RS2	88.92 $\pm$ 1.97 ns	11.08 $\pm$ 1.97 ns	0.26 $\pm$ 0.05 ns
RS3	88.76 $\pm$ 0.47 ns	11.24 $\pm$ 0.47 ns	0.27 $\pm$ 0.03 ns
RS4	88.69 $\pm$ 0.04 ns	11.31 $\pm$ 0.04 ns	0.38 $\pm$ 0.07 ns
Cooked biscuits			
B_CS	97.09 $\pm$ 0.24 ns	2.91 $\pm$ 0.24 ns	0.56 $\pm$ 0.02 ns
B_RS1	97.65 $\pm$ 0.41 ns	2.34 $\pm$ 0.41 ns	0.50 $\pm$ 0.04 ns
B_RS2	97.77 $\pm$ 0.25 ns	2.23 $\pm$ 0.25 ns	0.64 $\pm$ 0.01 ns
B_RS3	97.67 $\pm$ 0.25 ns	2.33 $\pm$ 0.25 ns	0.71 $\pm$ 0.14 ns
B_RS4	96.55 $\pm$ 0.96 ns	3.45 $\pm$ 0.96 ns	0.64 $\pm$ 0.05 ns

Values are the mean of three replicates $\pm$ standard deviation. 'Ns' indicates that no significant differences were found according to one-way ANOVA performed separately for raw and cooked biscuits.

This presents a potential dilemma as the inclusion of enrichment material, especially when a higher fibre content, can render the biscuits too dry for optimal texture (Burton-Freeman *et al.*, 2016).

In raw biscuits, CS exhibited the lowest TPC (26.81 ± 3.45 mg/g). Biscuits enriched with raspberry powder showed an increasing TPC with higher levels of enrichment, ranging from RS1 (43.90 ± 1.72 mg/g) to RS4 (64.73 ± 2.51 mg/g) (Table 4). Consistently, the RSA measured by ABTS followed a similar trend, with CS showing the lowest activity ($31.77 \pm 3.03\%$) and increasing in RS-enriched biscuits, from RS1 ($38.47 \pm 0.48\%$) to RS4 ($44.41 \pm 2.56\%$). The antioxidant capacity measured by DPPH was significantly higher in RS-enriched biscuits compared to CS. CS had the lowest activity ($24.30 \pm 0.75\%$), whereas the values increased markedly in RS1 ($68.04 \pm 0.40\%$), RS2 ($83.47 \pm 0.50\%$), RS3 ($80.71 \pm 0.25\%$), and RS4 ($85.07 \pm 0.01\%$). The enrichment of biscuits with raspberry powder is grounded in the substantial body of research highlighting the health benefits associated with berries, particularly red raspberries. Much of the early work in red raspberry research, was motivated by the discovery of their antioxidant properties and potential for health benefits (Burton-Freeman *et al.*, 2016). These studies have demonstrated that raspberries are rich in bioactive polyphenols, which can contribute to cardio-metabolic and neuronal health. Raspberry powders were found to contain nine different types of phenolic compounds, with significantly concentrations of ellagic acid, ellagic acid derivatives, and rutin, leading to a significant antioxidant potential (Rózyło *et al.*, 2023). By incorporating raspberry powder into the biscuits, these

Table 4 Total polyphenol content (TPC expressed as mg/g fw), radical scavenging activity (%) analysis by ABST, and DPPH assay in raw conventional biscuits (CS) and raw biscuits raspberry powder enriched (RS1, RS2, RS3, and RS4), and in cooked conventional biscuits (B_CS) and cooked biscuits raspberry powder enriched (B_RS1, B_RS2, B_RS3, and B_RS4)

	TPC (mg/g fw)	RSA ABTS (%)	RSA DPPH (%)
Raw short-crust pastry			
CS	26.81 ± 3.45 c	31.77 ± 3.03 c	24.30 ± 0.75 e
RS1	43.90 ± 1.72 b	38.47 ± 0.48 b	68.04 ± 0.40 d
RS2	46.64 ± 3.91 b	40.75 ± 0.97 ab	83.47 ± 0.50 b
RS3	55.54 ± 2.58 ab	41.92 ± 1.59 ab	80.71 ± 0.25 c
RS4	64.73 ± 2.51 a	44.41 ± 2.56 a	85.07 ± 0.01 a
Cooked biscuits			
B_CS	27.40 ± 2.58 d	33.77 ± 2.97 d	51.90 ± 1.20 d
B_RS1	64.14 ± 4.92 c	47.10 ± 0.83 c	89.33 ± 0.15 a
B_RS2	74.56 ± 4.78 c	51.59 ± 1.17 c	87.68 ± 0.40 b
B_RS3	116.83 ± 3.40 b	63.26 ± 1.66 b	88.48 ± 0.10 ab
B_RS4	231.89 ± 6.08 a	87.91 ± 3.11 a	85.07 ± 0.10 c

Values are the mean of three replicates ± standard deviation. Different letters within columns represent significant differences according to one-way ANOVA and Tuckey post hoc test with $P \leq 0.05$ performed separately for raw and cooked biscuits.

bioactive compounds enhanced the nutritional profile and health benefits of the final product.

Interestingly, cooking slightly increased the TPC in conventional biscuits (B_CS) to 27.40 ± 2.58 mg/g. A significant increase in TPC was also observed in cooked RS-enriched biscuits, particularly in B_RS3 (116.83 ± 3.40 mg/g) and B_RS4 (231.89 ± 6.08 mg/g), compared to their raw counterparts. The ABTS scavenging capacity, also increased after cooking, with B_CS at $33.77 \pm 2.97\%$, and higher values for RS-enriched biscuits, reaching up to $87.91 \pm 3.11\%$ in B_RS4. DPPH showed a notable increase in cooked biscuits compared to raw samples. B_CS had $51.90 \pm 1.20\%$, while RS-enriched biscuits showed very high RSA values, with B_RS1 ($89.33 \pm 0.15\%$), B_RS2 ($87.68 \pm 0.40\%$), B_RS3 ($88.48 \pm 0.10\%$), and B_RS4 ($85.07 \pm 0.10\%$). The presented data indicate that the inclusion of raspberry powder significantly enhances the phenolic content and antioxidant capacity of both raw and cooked biscuits. The increase is more pronounced in cooked biscuits, suggesting that the baking process may further release or activate phenolic compounds and enhance antioxidant activity. As noted by other authors (Kowalczewski *et al.*, 2019; De Santis *et al.*, 2022; Merendino *et al.*, 2023), the antioxidant activity increased values in DPPH and ABTS after the cooking treatment.

Baking has a significant impact on the antioxidant activity of food products. Different baking conditions, such as temperature and time, can affect the antioxidant properties of baked goods (Shen *et al.*, 2019).

Previous studies reports that the incorporation of functional ingredients, such as polyphenols, before baking can enhance the antioxidant activity of cookies as well as increases the oxidative stability (Pop *et al.*, 2023). Similarly, incorporating phenols-rich materials with wheat bread has been identified as an effective technique to improve the antioxidant potential of the final product (Leliana *et al.*, 2023). Specifically, the Maillard reaction, which occurs during baking, leads to the formation of new antioxidant compounds (Shen *et al.*, 2019). The Maillard reaction, a non-enzymatic browning process occurring during baking, is well-known for its ability to produce compounds with antioxidant properties. Maillard reaction products (MRPs) have been demonstrated to possess significant antioxidant activity, which is a key factor in food preservation and health benefits. The Maillard reaction yields a complex mixture of MRPs, each contributing differently to the antioxidant and stability properties of food (Shen *et al.*, 2019). MRPs are known for their excellent antioxidant abilities, achieved through mechanisms such as chelation of metal ions, breakdown of radical chains, and scavenging of reactive oxygen species. These properties make MRPs valuable enhancing the nutritional quality of food products Maillard reaction chemistry in formation of critical intermediates and flavour compounds and their antioxidant properties (Shakoor *et al.*, 2022). In recent research, the Maillard reaction has been explored under various conditions to develop functional biscuits with enhanced health benefits. These studies have highlighted the potential of the Maillard reaction to increase antioxidant activity, paving the way for the creation of health-promoting baked goods (Virág *et al.*, 2013). In our study, the increase in polyphenols and antioxidant activity observed after baking the raspberry powder-enriched biscuits can be attributed to these factors. The baking process likely facilitated the release and transformation of bioactive compounds, enhancing their availability and efficacy. The interaction between the raspberry polyphenols and the baking conditions (temperature and time) promoted the formation of additional antioxidant compounds, further boosting the antioxidant properties of the final product. This aligns with previous findings on the impact of baking on the antioxidant activities of food products. In conclusion, the balance in moisture content and texture observed in RS1 and RS2 makes them potentially more suitable for consumer acceptance, combining enhanced nutritional benefits without compromising sensory qualities.

Sensory descriptive test

The definition of the lexicon for the sensory description of the biscuits, conducted by the trained panel,

Table 5 Sensory descriptors ranked by their level of discrimination on products, along with their corresponding *P*-values

Descriptors	Test value	<i>P</i> -value
Caramel	4374	0.000
Hardness	4041	0.000
Friability	3959	0.000
Fruity	3900	0.000
Sour	3854	0.000
Persistence	3421	0.000
Sweet	3313	0.000
Buttery	3286	0.001
Colour intensity	3224	0.001
Bitter	2625	0.004
Cohesion	2625	0.004

allowed for the selection of specific descriptors to be included in the form for subsequent sensory tests. The sensorial descriptive test on the four types of biscuits was useful for selecting the optimal percentage of integration capable of minimising the penalty in the formation of the gluten network while guaranteeing an increase in functional properties.

The data collected were processed according to the product characterisation test by XLSTAT software, an analytical method that helps to determine which descriptors are better than others to discriminate the products evaluated by the judges in a sensory study.

This approach also helps characterise the sensory profile through the most essential product's sensory descriptors.

The primary goal of applying an ANOVA model to each descriptor is to determine if the judges' scores play a significant role in distinguishing the samples. The model evaluates the 'product' effect plus the 'judge' effect for each evaluation. The data processing result returns various coefficients of the model chosen for each combination product-descriptor. After analysing the data set using ANOVA, we obtain the *P* values

which estimate the impact of each descriptor on samples, judges, and their interactions. The descriptors are, therefore, classified according to decreasing discriminatory power (increasing *P* values). Table 5 presents the *t*-test values that are instrumental in assessing the discriminatory power of the various descriptors in a decreasing order, along with the *P* values of each. The *P* values lower than 0.05 confirm the high segregation potential of the descriptors, which contribute significantly to differentiating the samples. This approach allows us to characterise the sensory profile through the most important descriptors.

Observing the values, it is clear that caramel, hardness, and crumbliness represent the attributes that most characterise the products and significantly mark the differences between all the biscuits at all the proposed integration levels.

Descriptors with *P*-values <0.05 have promising segregation potential; Table 6 shows the contribution of each descriptor in separating each sample from the others. Table 7 and Figure S2a–e shows, respectively, the mean value and the model coefficients for each combination of product descriptors. Each value reported in the histograms, relating to each single descriptor, based on the model, indicates a significant discriminating positive (blue) or negative (red) effect on the characterisation of the product compared to all the others analysed. The colourless bars indicate those descriptors that do not characterise the product significantly compared to the others.

Upon observation, it becomes evident that B_CS, unenriched, and B_RS1, with minimal integration of raspberry powder (replacement flour 2.6% approx.), are primarily characterised by buttery notes and sweetness. As the enrichment of raspberry powder increases, the aroma significantly shift towards caramel and fruity notes. Simultaneously, the tasting notes become more intense and persistent, with the emergence of acidity and bitterness. The hardness and fragility also

Table 6 Model Coefficients: Various coefficients of the model chosen for each product–descriptor combination and *P*-value

Descriptors	B_CS		B_RS1		B_RS2		B_RS3		B_RS4	
	Coefficient	<i>P</i> -value	Coefficient	<i>P</i> -value	Coefficient	<i>P</i> -value	Coefficient	<i>P</i> -value	Coefficient	<i>P</i> -value
Caramel	−1550	<0.0001	−0.800	0.002	0.200	0.347	0.700	0.005	1450	<0.0001
Hardness	−1250	<0.0001	−0.500	0.036	−0.500	0.036	1000	0.001	1250	<0.0001
Friability	−0.850	0.001	−0.850	0.001	−0.100	0.594	1150	<0.0001	0.650	0.004
Fruity	−2650	<0.0001	0.100	0.776	0.600	0.107	0.100	0.776	1850	0.000
Sour	−0.900	0.002	−0.900	0.002	−0.400	0.109	0.600	0.023	1600	<0.0001
Persistence	−1350	0.002	−1600	0.001	0.650	0.087	0.900	0.024	1400	0.002
Sweet	1300	0.001	1050	0.003	−0.700	0.031	−0.700	0.031	−0.950	0.006
Buttery	1100	0.002	1100	0.002	−0.150	0.609	−0.900	0.008	−1150	0.002
Colour intensity	−1150	0.003	−0.900	0.013	−0.150	0.635	0.600	0.075	1600	0.000
Bitter	−0.800	0.011	−0.550	0.062	−0.050	0.855	0.200	0.469	1200	0.001
Cohesion	0.800	0.011	0.550	0.062	0.300	0.284	−0.700	0.023	−0.950	0.004

Table 7 Adjusted Averages by Product: This table displays the adjusted mean for each product-descriptor combination. Colours indicate a significant positive effect (blue) and a significant negative effect (red)

Samples	Caramel	Colour Intensity	Bitter	Sour	Hardness	Persistence	Friability	Fruity	Sweetness	Cohesion	Buttery
B_RS4	4.750	4.750	3.000	3.500	5.000	4.750	4.000	4.750	2.000	2.250	1.250
B_RS3	4.000	3.750	2.000	2.500	4.750	4.250	4.500	3.600	2.250	2.500	1.500
B_RS2	3.500	3.000	1.750	1.500	3.250	4.000	3.250	3.500	2.250	3.500	2.250
B_RS1	2.500	2.250	1.250	1.000	3.250	1.750	2.500	3.000	4.000	3.750	3.500
B_CS	1.750	2.000	1.000	1.000	2.500	2.000	2.500	0.250	4.250	4.000	3.500

Colours indicate a significant positive effect (blue) and a significant negative effect (red).

increase proportionally due to the progressively lower gluten content of the flour being substituted with raspberry powder. Sample B_RS2, with a 2.32% raspberry powder addition (replacement flour 5.3% approx.), demonstrates an excellent balance between aroma and structure. The light acidity of the raspberry effectively mitigates the buttery notes, while the fruity note is well-balanced, and negative notes of bitterness and caramel are not prominent. This equilibrium represents a significant achievement in product development. However, it is crucial to remember that maintaining a good structure with acceptable cohesion and friability is not just a goal, but a necessity. Higher increment values result in a penalty on the structure, making the product less acceptable. This is a stark reminder of the importance of structure in our products.

In samples B_RS3 and B_RS4 (replacement flour 8.20% and 11.23% approx., respectively), the further enrichment with raspberry powder in the dough leads to a substantial increase in friability and hardness, with a simultaneous dramatic loss of cohesion. These changes in consistency, relating to the partial replacement of the flour with a non-gluten and poorly hydrated matrix, excessively penalise the two products. Furthermore, the buttery and sweetness decrease, while, especially in sample B_RS4, the bitterness and the caramel note become dominant in the aroma, thus appearing highly unbalanced.

Consumer sensory evaluation

Although the sensory profile demonstrated that the product B_RS2 gave better results than all others, we also wanted to collect the opinions of the thirty-three consumers regarding all the experimental variations. Consumers were asked to express a preference score for each sample tasted, comparing them with each other. Consumers were free to re-taste the samples as many times as necessary, preferring the reformulated B_RS2 biscuit even to the one not enriched in raspberry powder, confirming the results of the sensory profile (Table 8). From the results of the preference test, it can be observed that the addition of raspberry

Table 8 Mean of preference evaluation expressed to consumer tasting short-crust biscuit samples

	B_CS	B_RS1	B_RS2	B_RS3	B_RS4
Preference	2.758 b	3.576 c	4.424 d	2.314 b	1.603 a
±ds	0.371	0.494	0.617	0.448	0.320

Different letters correspond to significant difference for $P < 0.05$.

powder is still appreciated, up to, obviously, a certain extent, beyond which the disadvantage of the physical structure prevails compared to the advantage of the fruity aroma, as suggested from the characterisation test performed on the sensory profile data.

Conclusion

The work allowed us to experiment and evaluate the acceptability of reformulating a simple, familiar, and widely consumed product such as short-crust biscuits. Our goal of using a waste plant product, such as raspberry powder, for supplementation is in line with the general trend to avoid as much as possible the use of synthetic products to increase the nutritional and functional value or improve the stability of food products, reduce processing waste from the processing industry, and, last but not least, redevelop the waste itself.

Scientific evidence confirms that raspberry powder, proving its phenolic richness and high antioxidant activity, could transfer these values to enriched foods. Moreover, the significant increase in the antioxidant capacity of our reformulated biscuits is a promising development.

The sensorial characterisation allowed us to verify even the tiny variations compared to the classic biscuit and identify the correct dose of enrichment. The consumer preference test confirmed the acceptability and high level of satisfaction.

The experimental biscuits object of this study can be considered a valid substitute for breakfast biscuits, and raspberry powder, a by-product of juice production, demonstrates the potential of transforming waste into a valuable resource.

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Author contributions

Diana De Santis: Conceptualization; methodology; data curation; investigation; supervision; funding acquisition; writing – original draft; writing – review and editing; software. **Serena Ferri:** Data curation; formal analysis; methodology. **Alice Rossi:** Formal analysis; methodology. **Riccardo Frisoni:** Methodology; formal analysis. **Margherita Modesti:** Conceptualization; data curation; software; writing – original draft; writing – review and editing; investigation.

Conflict of 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.

Ethics statement

The sensory and consumers tests were carried out in accordance with established ethical guidelines of the Declaration of Helsinki, accordingly, written informed consent has been obtained from every participants, after the nature of the study has been explained in understandable terms and all of them participated voluntarily. Participants were provided with a detailed explanation of the study's purpose, procedures, and use of the data, and they voluntarily agreed to participate via the statement 'I am aware that my responses are confidential, and I agree to participate in this survey'. An affirmative reply was required to enter the survey. The questionnaires used in the study were provided to participants ensuring clarity and comprehensibility. The study was conducted with the utmost respect for participants' rights and confidentiality. Any identifiable information collected from participants was anonymised to protect their privacy. The methodology employed in this study was designed to minimise potential harm or discomfort to participants while maximising the validity and reliability of the results. Sensory panellist and consumers were able to withdraw from the survey at any time without giving a reason. The products tested were safe for consumption.

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Peer review

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Data availability statement

All data generated or analysed during this study are included in the article or supplementary material.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Workflow for biscuit development.

Figure S2. Model coefficients for each product-descriptor combination in control biscuits (CS) and raspberry enriched biscuits (RS1, RS2, RS3, RS4). The colours correspond to a significant positive effect (blue) and a significant negative effect (red).