Journal of Food Measurement and Characterization
https://doi.org/10.1007/s11694-025-03198-6

ORIGINAL PAPER

Influence of semolina cream addition on the bioaccessibility of polyphenols in walnut-filled pastry (Şöbiyet)

Sena Bakir[1,2] · **Senem Kamiloglu**[3,4] · **Tugba Ozdal**[5] · **Esra Capanoglu**[6]

Received: 6 August 2024 / Accepted: 13 March 2025
© The Author(s) 2025

Abstract

Walnuts are widely consumed around the world, and are often used as a filling for pastries, especially in East Asia. In this study, a popular pastry called "şöbiyet" was examined to evaluate the interactions between semolina cream and walnuts. The phenolic profile, antioxidant activity, and in vitro bioaccessibility were analyzed. Samples containing 35% (W35%) and 20% (W20%) walnuts (w/w) were prepared with and without the addition of semolina cream. Total phenolic content (TPC) of undigested samples ranged from 417.6 ± 73.11 mg GAE 100 g^{-1} sample to 726.2 ± 21.66 mg GAE 100 g^{-1} sample. Although samples with added semolina cream showed higher TPC levels, the differences were not statistically significant ($p > 0.05$). In contrast, total antioxidant activity (TAC) levels, as measured by the DPPH and CUPRAC assays, indicated that the addition of semolina cream significantly decreased antioxidant activity ($p < 0.05$). A similar trend was observed in the in vitro bioaccessibility of individual phenolic compounds. In most cases, no significant differences were observed between samples with higher walnut content (W35%) regardless of whether they contained semolina cream ($p > 0.05$). However, samples with lower walnut content (W20%) lost some of the phenolic compounds, TPC and TAC during intestinal digestion phase when semolina cream was added ($p < 0.05$). Overall, the results highlighted that adjusting the walnut content and semolina cream composition in pastries can improve the bioaccessibility of polyphenols, suggesting potential applications in the development of functional foods with enhanced health benefits.

Keywords Walnut-filled pastry · Co-digestion · Antioxidant capacity · Flavonoids · Phenolic acids

Introduction

Walnuts (*Juglans regia* L.), the most widely distributed tree nut worldwide, have long been valued as a nutrient-dense food in many nations [1, 2]. These nuts are recognized for their lipid profile, especially their essential fatty acid content [3], as well as a range of other bioactive compounds, such as polyphenols [4]. Phenolic compounds, one of the most prevalent classes of phytochemicals, are divided into several subclasses, including tannins, coumarins, stilbenes, phenolic acids, and flavonoids. Due to their anti-aging, anti-carcinogenic, anti-bacterial, anti-fungal, anti-inflammatory, and

✉ Sena Bakir
sena.bakir@erdogan.edu.tr

Senem Kamiloglu
skamiloglu@uludag.edu.tr

Tugba Ozdal
tugba.ozdal@okan.edu.tr

Esra Capanoglu
capanogl@itu.edu.tr

[1] Department of Gastronomy and Culinary Arts, Tourism Faculty, Recep Tayyip Erdogan University, 53400, Ardesen, Rize, Türkiye

[2] Blueberry Application and Research Center, Recep Tayyip Erdogan University, Rize, Türkiye

[3] Department of Food Engineering, Faculty of Agriculture, Bursa Uludag University, 16059, Gorukle, Bursa, Türkiye

[4] Science and Technology Application and Research Center (BITUAM), Bursa Uludag University, 16059, Gorukle, Bursa, Türkiye

[5] Department of Food Engineering, Faculty of Engineering and Natural Sciences, Istanbul Okan University, 34959, Tuzla, Istanbul, Türkiye

[6] Department of Food Engineering, Faculty of Chemical and Metallurgical Engineering, Istanbul Technical University, 34469, Maslak, Istanbul, Türkiye

Published online: 30 March 2025

neuroprotective properties, phenolic compounds are potentially valuable to human health [5, 6]. The antioxidant activity associated with phenolic compounds contributes to these health benefits, including anti-aging, anti-carcinogenicity, and anti-mutagenicity properties [7]. Among various tree nuts, walnuts have significantly higher total phenolic content (TPC) and total antioxidant capacity (TAC) compared to almonds, hazelnuts, cashews, and peanuts [8].

There is a growing demand for innovative, high-quality products that cater to specific dietary needs, such as pastries for people with low blood sugar. Consumers seeking unique, healthy options are particularly interested in baked goods made with ingredients like partially defatted walnut flour, which have been shown to be well-received in sensory evaluations [9, 10]. Traditional food products, such as bread with walnut powders and halva with chopped walnut kernels [11] are also appealing choices. One such pastry is "şöbiyet", a type of baklava traditionally shaped into triangular layers of thin dough filled with semolina cream and walnuts or pistachios.

The phenolic compounds in walnuts can interact the proteins in dough and semolina cream, potentially affecting the digestibility of these compounds. These interactions can be reversible, involving non-covalent forces like hydrogen bonds, hydrophobic interactions, and van der Waals forces, or irreversible, involving covalent bonds [12]. Additionally, the stages of digestion in the gastrointestinal system can alter these interactions. While simulated in vitro gastrointestinal digestion models cannot fully replicate in vivo conditions, they are valuable for studying the effects of food matrices on bioaccessibility and for providing preliminary insights to support in vivo research [13]. Factors such as type of milk, sugar addition, and the wheat flour used in dough preparation can influence the bioaccessibility of phenolic compounds in walnut pastry. It has been suggested that combining sugar or sweeteners with flavonoid-rich foods enhances the overall recovery of flavonoids during digestion [14]. On the other hand, since antioxidants have different polarities, the effectiveness of extraction depends on both the solvent and extraction technique. It has been reported that phenolic compounds can be extracted from various matrices using a range of extraction techniques and solvents with different polarities [15]. The use of different solvents, particularly ethanol and methanol, in extraction protocols has been widely reported in previous studies. When comparing methanolic and ethanolic extractions, studies have indicated that while ethanol was more effective in extracting phenolic compounds, methanolic extracts exhibited higher antioxidant activity than both ethanolic and aqueous extracts, and were also more effective in scavenging free radical [16]. Moreover, ultrasound-assisted extraction protocol is a well-known method for extracting phenolic compounds from undigested samples. This technique uses ultrasonic waves to create cycles of expansion and compression, leading to cavitation that breaks down cell walls and improves solvent penetration by causing cell rupture near the solid surface [17].

To our knowledge, there are no published studies investigating the interaction of walnut polyphenolic compounds with semolina cream. For this purpose, the aim of this study is to examine the bioaccessibility and antioxidant activity of walnut powders used in semolina cream added pastries. To achieve this, components of pastry were separately analyzed. Matrix effects on walnut polyphenols were evaluated through in vitro digestion and methods by spectrophotometric and chromatographic methods.

Materials and methods

Formulations

Four formulations were used to prepare the walnut-filled pastry as shown in Table 1. These formulations were developed based on the expertise of field specialists. The semolina cream was made by combining goat milk and semolina flour (9%, w/w) in a pot over medium heat to form a thick pudding. The phyllo dough layers, made from starch, flour, egg and salt, served as the base for the walnut-filled pastry. Each layer was divided to small squares, and 20 layers were stacked on top of each other. Butter was sprinkled between the layers, and semolina cream was poured onto the center of the square-shaped layers. Walnut flour was added on top of the semolina cream, and the dough layers were folded into triangles. The prepared samples were baked in an industrial oven at 200–210 °C for approximately 30 min. After cooling to room temperature, the final products were immediately used for further analysis.

Chemicals

All chemicals and reagents used in the current study were either analytical or HPLC-grade. For the simulation of in vitro digestion, enzymes including pepsin (from porcine

Table 1 The walnut-filled pastry formulations prepared in this study*

Formulations**	Walnut (%)	Semolina cream (%)	Dough (%)
W35%	38	–	62
W35% + S	35	8	57
W20%	25	–	75
W20% + S	20	10	70

*Values in the table were given as weight basis

**The amounts of walnut and dough in the samples were kept constant and in some formulations semolina cream was added

gastric mucosa), pancreatin (from porcine pancreas), and bile were purchased from Sigma–Aldrich (Steinheim, Germany). The quantification of major polyphenols was carried out using gallic acid, (−)-catechin, (−)-epigallocatechin gallate 2,3,4-trihydroxybenzoic acid, vanilic acid, syringic acid, ellagic acid, ferulic acid, naringin (Sigma-Aldrich) as external standards.

In vitro digestion

The INFOGEST in vitro digestion model [13, 18] was used to simulate sequential gastric and intestinal digestion. The contents of gastric and intestinal fluids were identical to those specified in the INFOGEST technique. To simulate gastric digestion, 5 g of walnut-filled pastry, 6 mL of gastric fluid, 1.28 mL of pepsin solution (25,000 U/mL), 4 µL of calcium chloride (0.3 M), and 6 M HCl were mixed. The pH was then adjusted to 3. Distilled water was added to bring the mixture's total volume to 8 mL, and the mixtures were incubated (Nüve ES 120, Ankara, Turkey) for 2 h at 37 °C while being continuously stirred. For every formulation, 2 mL aliquots were taken once the simulated gastric digestion was finished. The remaining mixture was combined with 7.7 mL of intestinal fluid, 3.5 mL of pancreatin solution (800 U/mL), 1.75 mL of bile (160 mM), and 28 µL of calcium chloride (0.3 M) to simulate intestinal digestion. The pH of the mixture was adjusted to 7 using 1 M NaOH, and distilled water was used to bring the mixture's total volume to 14 mL. The mixes were again incubated for 2 h at 37 °C while being constantly stirred. Once the simulated intestinal digestion was finished, 2 mL aliquots were taken for every formulation.

Additionally, to account for interferences from the digestive secretions, a blank sample was included and incubated under the same conditions. Following the simulated stomach and intestinal digestion, enzyme inactivation was performed by adjusting the pH to 2 with formic acid, following centrifugation at 23,000 × *g* for 10 min. The supernatants were filtered, and spectrophotometric assays were used to measure the TPC and TAC. A chromatographic technique was used to measure the individual polyphenols.

Extraction of polyphenols

Aqueus-methanol extracts were prepared according to Bakir et al. [19] with slight modifications. 2 g of homogenized sample was weighed, and 10 mL of 75% MeOH containing 0.1% formic acid was added. The mixture was ultrasonicated for 15 min at 4 °C (USC900TH, VWR ultrasonic cleaner, Radnor, PA, USA) and then centrifuged for 10 min at 4 °C and 9500 × *g* (Hettich Universal 32R, Tuttlingen, Germany). The supernatants were then filtered through 0.45 µm filter membranes and kept at − 20 °C until analysis.

Spectrophotometric analysis

Using a UV–Vis spectrophotometer (Optima SP-3000 nano, Tokyo, Japan), TPC and TAC of the samples were determined. The Folin-Ciocalteu reagent was used to measure the TPC as previously described by Singleton et al. [20] and the results were given as mg of gallic acid equivalent (GAE) per100 g of sample (linear range: 1–600 ppm, $R^2 = 0.997$). TAC was measured with DPPH (2,2-diphenyl-1-picrylhydrazyl) [21] and CUPRAC (cupric ion reducing antioxidant capacity) [22] assays. The results of both assays were reported in mg of Trolox® equivalent (TE) per 100 g of sample ($R^2 \geq 0.993$; linear ranges: 1–200 and 1–600 ppm for DPPH and CUPRAC, respectively). In spectrophotometric assays, measured values were acquired empirically through evaluation of the walnut-filled pastry and co-ingested samples, whereas calculated values were computed mathematically as the sum of walnut + semolina cream + dough.

Chromatographic analysis

An earlier approach [19] was used for the chromatographic analysis of semipolar compounds, utilizing a Waters 2695 HPLC connected to a Waters 2996 PDA detector (Waters Corp., Milford, MA, USA). Chromatographic separation was achieved using a Supelcosil C18 250 × 4.6 mm, 5 µm column (Sigma-Aldrich) at 40 °C. At a flow rate of 1 mL/min, 10 µL of samples that had been passed through 0.45 µm membrane filters were injected into the system using mobile phases A (TFA:MilliQ water, 1:1000, v/v) and B (TFA:acetonitrile, 1:1000, v/v). This was the linear gradient: 5% B at 0 min, 35% B at 0–45 min, 75% B at 45–47 min, 35% B at 47–49 min, and 50 min of returning to starting conditions. Measurements of the spectrum were taken at 280, 320, and 360 nm. The following standards were used to quantify polyphenols: gallic acid, 2,3,4-trihydroxybenzoic acid, vanilic acid, syringic acid, ellagic acid, ferulic acid, (−)-catechin, (−)-epigallocatechin gallate, and naringin. The selection of phenolic standards was based on their abundance in walnuts. The results showed acceptable linearity ($R^2 \geq 0.992$) within the specified range (0.1–200 ppm). The findings were reported in mg per 100 g^{-1} sample.

Statistical analysis

Three biological (i.e., repetition using the same formulation) and three technical (i.e., measurements made for each test) replicates were used for each analysis. Statistical analysis was performed using SPSS software (version 21, Chicago, IL, USA). A one-way ANOVA

was employed to compare the treatments, and a Tukey post hoc test was conducted with a significance level of $p < 0.05$.

Results and discussion

Spectrophotometric analysis

The changes in the TPC of walnut-filled pastry after

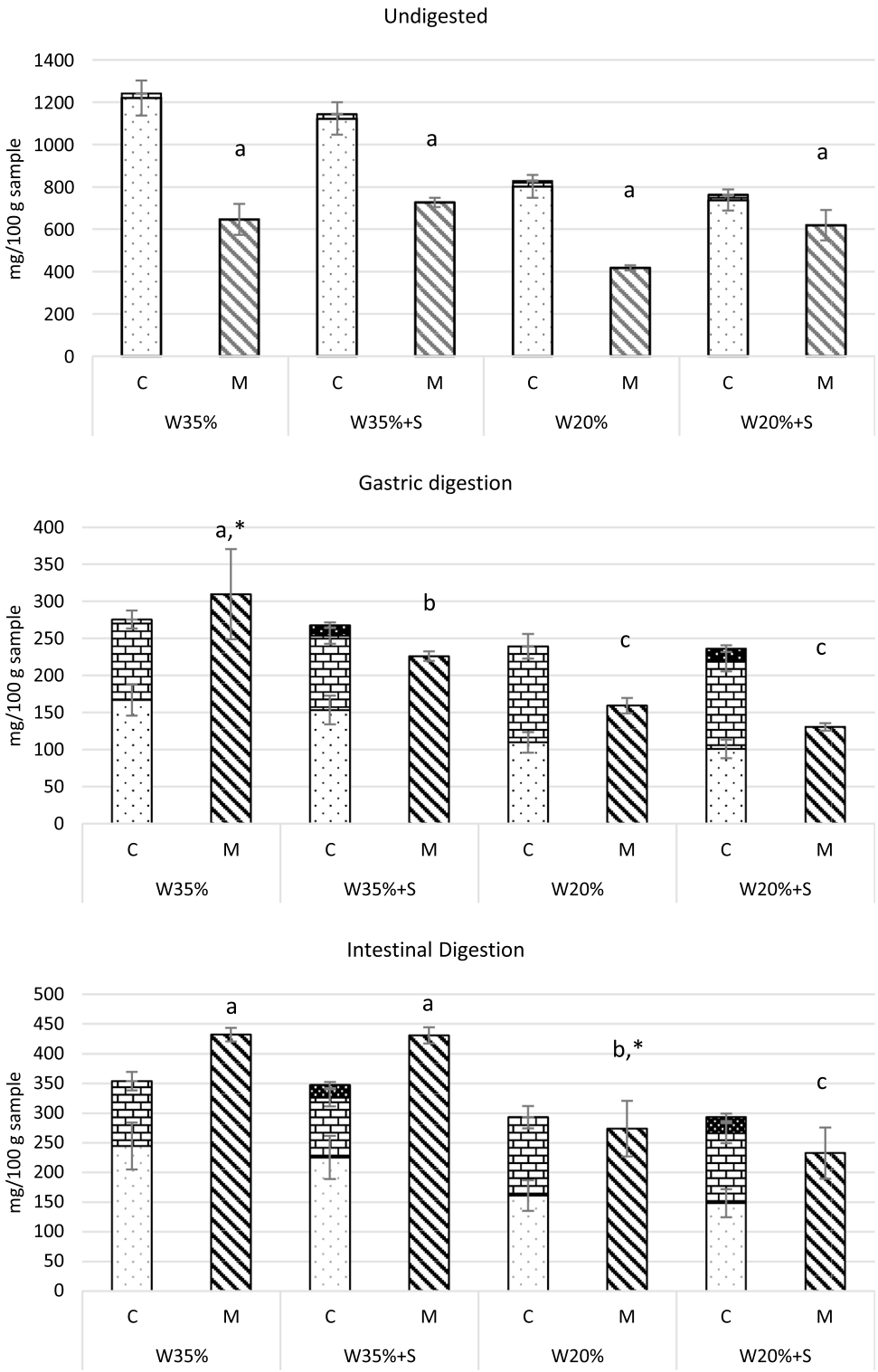


Fig. 1 Changes in the total phenolic content (TPC) of walnut-filled pastry after co-digestion with different amount of walnut (W35% and W20%) and semolina cream (S). different letters above bars represent statistically significant differences among samples ($p < 0.05$), whereas statistical differences between the calculated (C) and measured (M) values are donated as * $p < 0.05$.: walnut, : dough, : S, M

co-digestion with semolina cream are shown in Fig. 1. The TPC of walnuts used in this study was found to be 32.1 ± 1.52 mg GAE g^{-1} sample. TPC in walnut kernels has been reported in three different forms: free (51.1–68.1%), bound (21.0–38.0%), and esterified (9.7–18.7%). Methanol extracts demonstrated a high extraction efficiency of 7.49 mg GAE g^{-1} for bound phenolics (20 mg GAE g^{-1} DW) [23]. The calculated TPC values of undigested samples were higher than measured values ($p < 0.05$). As expected, W35% samples exhibited more TPC than W20% ones, regardless of the addition of semolina cream. Although, the TPC of all four prepared samples ranged from 417.6 ± 73.11 mg GAE 100 g^{-1} sample to 726.2 ± 21.66 mg GAE 100 g^{-1}sample, there were no significant differences between samples ($p = 0.197$). However, slight increases in TPC were observed for measured values with the addition of semolina cream. Overall, the considerably lower measured values compared to calculated ones indicated that the extractability of phenolic compounds was affected by the food matrix. Gastric and intestinal digestion stages revealed significant differences between calculated and measured values for almost all prepared samples ($p < 0.05$, except where indicated with * on graphics). The addition of semolina cream affected the behavior of TPC differently during digestion phases. For instance, the intestinally digested amount of TPC was higher in both W35% and W20% (> 65%), whereas it dropped by about 60% for W35% and 38% for W20% with semolina cream addition. The significant reduction in TPC during intestinal digestion can be attributed to a matrix effect, where phenolic compounds become less extractable due to interactions with semolina proteins. Additionally, enzymatic hydrolysis and oxidative reactions occurring during digestion may further contribute to the degradation of phenolics, leading to lower detectable levels.

Changes in TAC of walnut-filled pastry are shown in Fig. 2. Two different assays, DPPH and CUPRAC, were used to measure the TAC levels. Both assays indicated that the differences between calculated and measured values were statistically significant for almost all digestion stages ($p < 0.05$). Interestingly, the digestion stages exhibited different outcomes for DPPH and CUPRAC assays. Nearly all the calculated values were higher than the measured values of CUPRAC assay, while contrary results were obtained by DPPH assay. Calculated values of CUPRAC assay were higher than those of DPPH assay at all digestion stages, which could be related to the reducing power of cupric ion, and higher selectivity of the CUPRAC method. Both TAC assays showed that the addition of semolina cream to the samples decreased the antioxidant activity in the undigested samples ($p < 0.05$). Clear differences can be observed in the gastric digestion phase, where measured values were elevated in the DPPH assay. Contrary to the TPC assay, the addition of semolina cream to pastry formulas increased the TAC of samples based on DPPH and CUPRAC assays for gastric-digested samples ($p < 0.05$). The intestinal digestion stage revealed that semolina addition did not exhibit statistical differences among W35% samples. It is possible that the semolina cream in the pastry formula can bind only a specific amount of phenolic compounds, which caused significant a decrease at lower amounts while did not cause a difference at relatively higher amounts. The differences observed between the CUPRAC and DPPH assays may be related to the fact that the CUPRAC assay can detect both hydrophilic and lipophilic antioxidants, while the DPPH assay is specific to hydrophilic antioxidants [24].

Chromatographic analysis

Chromatographic analysis has made it possible to identify non-flavonoid and flavonoid compounds, as shown in Table 2. A total of 25 phenolic compounds were identified in black walnut by Vu et al. [7], including phenolic acids (i.e., gallic acid, vanilic acid, syringic acid, ferulic acid) and flavonoid glycosides (i.e., catechin, naringin). The phenolic compounds in semolina were found to be insignificant compared those in walnuts and were elucidated accordingly. However, cereal grains are generally an important source of phenolic compounds [25, 26]. Since refined flour or semolina is commonly consumed cereal-based foods like bread and pasta, these products typically do not contain phenolic compounds. Flour and semolina are derived from the starchy endosperm layer of cereal grains, while the majority of bioactive compounds are found in the outer layers, which are removed as bran [27, 28]. Although the addition of semolina cream to the formula appeared to decrease the amount of identified compounds, no statistical differences were observed among W35% samples in undigested form ($p = 0.079$).

Ellagic acid was found to be the most abundant phenolic acid in the samples, accounting for approximately 30–47% of total non-flavonoid compounds. This compound was followed by ferulic acid, vanillic acid and gallic acid. It seems that the addition of semolina cream to pastry formulations caused a decrease in total non-flavonoid compounds (23–64%, $p < 0{,}05$). W35% samples did not differ statistically from each other despite the addition of semolina cream, whereas W20% samples exhibited statistical differences after the addition of semolina cream ($p < 0.05$). Adding semolina cream to W35% samples decreased the ellagic acid levels ($p < 0.05$). A higher walnut concentration results in a greater amount of phenolic compounds, which exceeds the binding capacity of semolina cream. Ellagic acid exhibited a notable decrease during gastric digestion, likely due to its sensitivity to acidic pH, whereas intestinal conditions facilitated some recovery, possibly due to interactions with bile salts. The intestinally digested amount of ellagic acid was approximately 37% and 71%

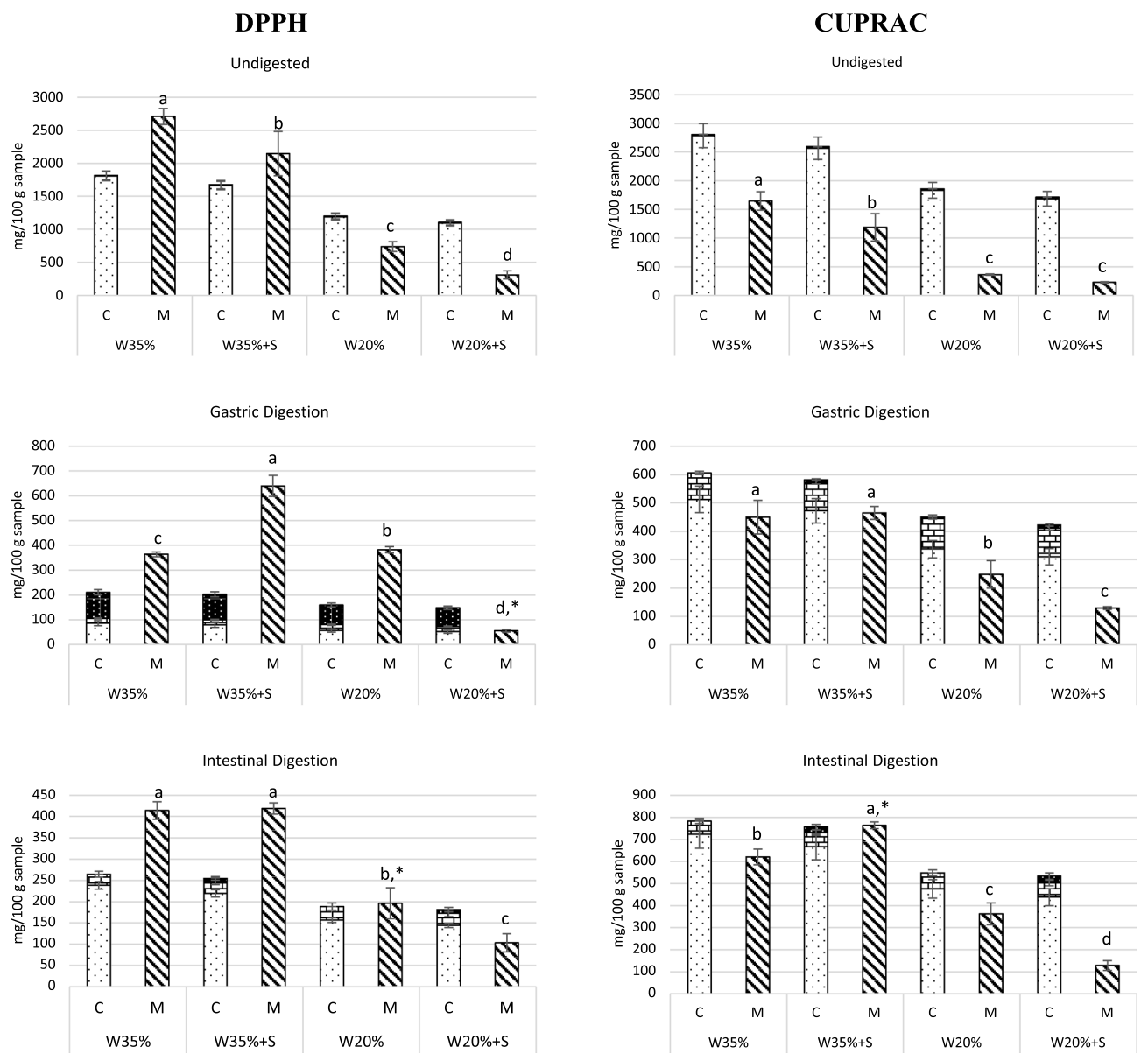


Fig. 2 Changes in the total antioxidant capacity (TAC) of walnut-filled pastry after co-digestion with different amount of walnut (W35% and W20%) and semolina cream (S). Different letters above bars represent statistically significant differences among samples ($p < 0.05$), whereas statistical differences between the calculated (C) and measured (M) values are donated as * $p < 0.05$: walnut, dough, S, M

of W35% and W20% samples, respectively. However, some compounds increased after simulated gastrointestinal digestion. The amount of ferulic acid reached more than 58% of the undigested versions for all prepared samples. Syringic acid was barely detectable in W35% samples and absent in W20% samples during the undigested phase. However, its levels increased significantly after gastric digestion, with even more pronounced rises observed following intestinal digestion. Significant changes in the physicochemical and structural characteristics of bioactive compounds, as well as various interactions leading to oxidation, the precipitation of phenolics with the digestive mixture's enzymes, and interactions with other substances like polysaccharides, may occur following intestinal digestion [29]. In a study involving peanuts, peeled and unpeeled hazelnuts, pistachios, almonds, and walnuts, in vitro digestion and fermentation processes were assessed [30]. The authors of this study emphasized that over time, low molecular weight phenolic compounds were formed as a result of the degradation of high molecular weight phenolics like flavonoids, lignins, and hydroxycinnamic acids. The food matrix found in the samples

Table 2 Changes in the flavonoid and non-flavonoid compounds of walnut-filled pastry after co-digestion with different amounts of walnut (W35% and W20%) and semolina cream (S)

Compounds	Sample	Undigested	Gastric digestion	Intestinal digestion
Gallic acid	W35%	$3.51 \pm 0.15^{a,A}$	$2.01 \pm 0.25^{a,C}$	$2.82 \pm 0.06^{a,B}$
	W35% + S	$3.85 \pm 0.34^{a,A}$	$2 \pm 0.16^{a,B}$	$2.67 \pm 0.04^{a,B}$
	W20%	$2.27 \pm 0.14^{b,A}$	$1.14 \pm 0.2^{b,C}$	$1.66 \pm 0.32^{b,AB}$
	W20% + S	$0.26 \pm 0.03^{c,C}$	$0.64 \pm 0.01^{b,B}$	$1.05 \pm 0.14^{c,A}$
2,3,4-trihydroxybenzoic acid	W35%	$3.35 \pm 0.21^{a,A}$	$2.17 \pm 0.28^{a,B}$	$2.99 \pm 0.\ 11^{a,A}$
	W35% + S	$2.73 \pm 0.26^{a,A}$	$1.58 \pm 0.29^{ab,B}$	$2.7 \pm 0.16^{a,A}$
	W20%	$1.89 \pm 0.26^{b,A}$	$0.91 \pm 0.1^{bc,B}$	$1.91 \pm 0.17^{b,A}$
	W20% + S	$1.08 \pm 0.09^{c,B}$	$0.5 \pm 0.01^{c,C}$	$1.36 \pm 0.01^{c,A}$
Vanilic acid	W35%	$3.89 \pm 0.4^{a,A}$	ND	$0.9 \pm 0.04^{a,B}$
	W35% + S	$2.78 \pm 0.44^{b,A}$	ND	$0.63 \pm 0.04^{b,B}$
	W20%	$0.76 \pm 0.14^{c,A}$	ND	$0.33 \pm 0.04^{c,B}$
	W20% + S	ND	ND	0.14 ± 0.01^{d}
Syringic acid	W35%	$0.14 \pm 0.01^{a,C}$	$0.83 \pm 0.16^{a,B}$	$3.72 \pm 0.31^{b,A}$
	W35% + S	$0.11 \pm 0.02^{a,C}$	$0.88 \pm 0.17^{a,B}$	$5.18 \pm 0.38^{a,A}$
	W20%	ND	$0.72 \pm 0.14^{a,B}$	$4.85 \pm 0.31^{a,A}$
	W20% + S	ND	$0.57 \pm 0.11^{a,B}$	$4.62 \pm 0.05^{ab,A}$
Ellagic acid	W35%	$13.73 \pm 1.89^{a,A}$	$1.25 \pm 0.17^{a,C}$	$4.87 \pm 0.47^{a,B}$
	W35% + S	$9.12 \pm 1.48^{b,A}$	$1.39 \pm 0.14^{a,B}$	$3.36 \pm 0.08^{b,B}$
	W20%	$3.25 \pm 0.23^{c,A}$	$0.51 \pm 0.1^{b,C}$	$2.01 \pm 0.31^{c,B}$
	W20% + S	$1.31 \pm 0.1^{c,A}$	$0.23 \pm 0.04^{b,C}$	$0.93 \pm 0.16^{d,B}$
Ferulic acid	W35%	$4.63 \pm 0.31^{a,B}$	$5.55 \pm 1.08^{a,B}$	$8.76 \pm 0.81^{a,A}$
	W35% + S	$4.1 \pm 0.32^{a,B}$	$4.51 \pm 0.29^{a,B}$	$6.48 \pm 0.41^{b,A}$
	W20%	$2.64 \pm 0.39^{b,B}$	$2.44 \pm 0.35^{b,B}$	$4.74 \pm 0.27^{c,A}$
	W20% + S	$1.27 \pm 0.11^{c,B}$	$1.1 \pm 0.07^{b,B}$	$2.98 \pm 0.28^{d,A}$
Total non-flavonoid	W35%	$29.25 \pm 2.97^{a,A}$	$11.81 \pm 1.94^{a,C}$	$21.07 \pm 1.69^{a,B}$
	W35% + S	$22.69 \pm 2.86^{b,A}$	$10.36 \pm 1.05^{a,B}$	$21.01 \pm 1.11^{a,A}$
	W20%	$10.82 \pm 1.17^{c,B}$	$5.72 \pm 0.88^{b,C}$	$15.49 \pm 1.42^{b,A}$
	W20% + S	$3.91 \pm 0.32^{d,B}$	$3.04 \pm 0.23^{b,B}$	$11.09 \pm 0.64^{c,A}$
(−)-Catechin	W35%	$2.69 \pm 0.28^{a,A}$	ND	$1.99 \pm 0.12^{a,B}$
	W35% + S	$2.06 \pm 0.34^{a,A}$	ND	$1.01 \pm 0.18^{b,B}$
	W20%	$0.99 \pm 0.13^{b,A}$	ND	$0.77 \pm 0.06^{b,A}$
	W20% + S	ND	ND	0.51 ± 0.04^{b}
(−)-Epigallocatechin gallate	W35%	$4.08 \pm 0.67^{a,A}$	ND	$0.55 \pm 0.04^{a,B}$
	W35% + S	$2.98 \pm 0.52^{a,A}$	ND	$0.34 \pm 0.05^{b,B}$
	W20%	$0.59 \pm 0.08^{b,A}$	ND	$0.35 \pm 0.05^{b,B}$
	W20% + S	ND	ND	0.14 ± 0.01^{c}
Naringin	W35%	$2.12 \pm 0.1^{a,A}$	$1.17 \pm 0.17^{a,B}$	$2.5 \pm 0.27^{a,A}$
	W35% + S	$1.85 \pm 0.18^{a,A}$	$1.07 \pm 0.08^{a,B}$	$1.79 \pm 0.15^{b,A}$
	W20%	$0.8 \pm 0.1^{b,B}$	$0.56 \pm 0.03^{b,C}$	$1.38 \pm 0.03^{bc,A}$
	W20% + S	ND	$0.32 \pm 0.02^{b,B}$	$1.03 \pm 0.19^{c,A}$
Total flavonoids	W35%	$8.88 \pm 1.06^{a,A}$	$1.17 \pm 0.17^{a,C}$	$5.04 \pm 0.43^{a,B}$
	W35% + S	$6.89 \pm 1.04^{a,A}$	$1.07 \pm 0.08^{a,C}$	$3.14 \pm 0.38^{b,B}$
	W20%	$2.38 \pm 0.31^{b,A}$	$0.56 \pm 0.03^{b,B}$	$2.5 \pm 0.14^{b,A}$
	W20% + S	ND	$0.32 \pm 0.02^{b,B}$	$1.68 \pm 0.23^{c,A}$

The data presented in this table is expressed as mg/100 g sample. Different capital letters in the rows indicate statistically significant differences between digestion stages, while different lowercase letters in the columns denote significant differences among pastry samples for each compound ($p < 0.05$). None of the compounds were detected in semolina cream and dough. ND: not detected

presented here may be connected to the divergent performances of bioactive compounds.

On the other hand, (−)-epigallocatechin gallate exhibited the highest concentration among the total flavonoid compounds (25–46%). The addition of semolina cream affected the total flavonoid compounds, and none of the flavonoid compounds were found in the W20% + S samples during the undigested phases. Similar to the non-flavonoid compounds, semolina cream did not alter the concentration of flavonoid compounds in W35% samples. The detected flavonoid compounds, (−)-catechin and (−)-epigallocatechin gallate were undetectable after gastric digestion, suggesting degradation in acidic conditions. However, a small fraction was retained post-intestinal digestion, likely due to re-release from bound complexes. The retention percentages of (−)-catechin and (−)-epigallocatechin gallate were 22–51 and 40–89%, respectively, except in the W20% + S sample. Naringenin content of the samples increased after intestinal digestion, except for W35% + S sample, where a 3.4% reduction was observed compared to the undigested phase ($p < 0.05$). Likewise, Goulas and Hadjisolomou [31] emphasized that during gastric digestion, the acidic environment can cause phenolic compounds, particularly phenolic acids, to be released from the food matrix (such as the cell wall) or increase their reactivity with the Folin-Ciocalteu reagent. Conversely, gastric conditions can lead to a decrease in flavonols and flavon-3-ols, such as (−)-catechin and (−)-epigallocatechin gallate. However, it has been demonstrated that intestinal digestion is primarily responsible for these changes.

The observed decrease in antioxidants with the addition of semolina cream may be related to the dilution effect, where semolina cream reduces the relative concentration of phenolic compounds in the sample, consequently lowering antioxidant activity. However, interactions between phenolic compounds and components in semolina cream, such as proteins, may also play a role. Semolina proteins can interact non-covalently with phenolic compounds through hydrogen bonding and hydrophobic interactions, potentially limiting their release during digestion. This binding effect may contribute to the lower bioaccessibility of phenolics in samples containing semolina cream. Such interactions could also affect the stability of certain polyphenols, as evidenced by the notable reduction in total non-flavonoid compounds and specific flavonoids like (−)-epigallocatechin gallate.

Overall, the findings of this study suggested that adjusting the walnut-to-semolina ratio can enhance the health benefits of pastries. Food manufacturers could explore alternative ingredient modifications, such as reducing the semolina content, to improve phenolic bioaccessibility in functional pastry formulations. Future in vivo studies are necessary to validate these findings and to better understand the bioavailability of polyphenols in a physiological environment. Investigating the metabolic fate of these compounds and their impact on oxidative stress biomarkers in human trials would provide further insights.

Conclusion

A walnut-filled pastry, şöbiyet, was investigated in this study to examine changes in phenolic content and antioxidant activity with the addition of semolina cream. For this purpose, samples containing different amounts of walnuts (W35% and W20%, w/w) were prepared with and without semolina cream. TPC of the undigested samples did not differ significantly from each other; however, simulated digestion phases exhibited differentiation among the prepared samples. Similarly, samples without semolina cream demonstrated higher TAC than those with semolina cream in most digestion phases. The behaviour of semipolar compounds in prepared samples was also investigated before and after in vitro digestion. Results indicated that the addition of semolina cream negatively affected the low walnut content samples, while high walnut content samples did not differ significantly from each other.

Semolina and goat milk in semolina cream caused the entrapment of phenolic compounds. Since the amount of semolina cream was kept constant and its total ratio remained lower, the amount of phenolic substance retained by the same amount of semolina cream remained constant. Therefore, the addition of semolina cream did not cause a significant difference in the samples containing more walnuts. Further research should explore alternative ingredients that minimize phenolic entrapment. Additionally, mechanistic studies on polyphenol–protein interactions in different food matrices are needed to optimize bioactive retention in functional foods.

Although this study provides valuable data for understanding the effects of semolina cream on walnut polyphenols, further research involving in vivo studies and applications in food media other than pastry products is required to fully characterize the matrix effect on walnut polyphenols. In this study, semolina cream was prepared using both semolina and goat milk, which suggests a potential synergistic effect. However, to gain a clearer understanding, an additional study is proposed to separately investigate the binding properties of semolina and its specific interactions with milk proteins. This focused research could provide valuable insights into these dynamics.

In practical terms, adjusting the walnut content in semolina-based fillings could improve the antioxidant properties of such pastries, aligning them more closely with the growing consumer demand for functional foods. Moreover, understanding the entrapment of phenolics by semolina cream points to potential formulation strategies in şöbiyet and similar pastries, where the use of alternative ingredients

or modifications in cream composition could further improve the release of bioactive compounds. By addressing these matrix effects, food scientists and manufacturers might better tailor traditional pastries to offer enhanced health benefits, potentially appealing to both the scientific community and health-conscious consumers in the food industry.

Acknowledgements The authors would like to thank Mr. Atakan Budumlu for his technical assistance.

Author's contribution Sena Bakir: Investigation, Formal analysis, Writing—original draft. Senem Kamiloglu: Conceptualization, Formal analysis, Investigation, Writing—review & editing. Tugba Ozdal: Conceptualization, Resources, Writing—review & editing. Esra Capanoglu: Resources, Writing—review & editing.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK).

Data Availability All data supporting this study are included in this manuscript. Further details are available from the corresponding author upon request.

Declaration

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.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

1. J. Regueiro, C. Sánchez-González, A. Vallverdú-Queralt, J. Simal-Gándara, R. Lamuela-Raventós, M. Izquierdo-Pulido, Food Chem. **152**, 340 (2014)
2. A. Shojaei, S. Rastegar, P. Sayyad-Amin, J. Food Meas. Charact. **17**, 3938 (2023)
3. M. Shahidi-Noghabi, S. Naji-Tabasi, M. Sarraf, J. Food Meas. Charact. **13**, 785 (2019)
4. C. Sánchez-González, C.J. Ciudad, V. Noé, M. Izquierdo-Pulido, Crit. Rev. Food Sci. Nutr. **57**, 3373 (2017)
5. K.B. Pandey, S.I. Rizvi, Oxid. Med. Cell. Longev. **2**, 270 (2009)
6. E. Ros, M. Izquierdo-Pulido, A. Sala-Vila, Curr. Opin. Clin. Nutr. Metab. Care **21**, 498 (2018)
7. D.C. Vu, P.H. Vo, M.V. Coggeshall, C.-H. Lin, J. Agric. Food Chem. **66**, 4503 (2018)
8. X. Wu, G.R. Beecher, J.M. Holden, D.B. Haytowitz, S.E. Gebhardt, R.L. Prior, J. Agric. Food Chem. **52**, 4026 (2004)
9. J.C.M. Barreira, M.A. Nunes, B.V. da Silva, F.B. Pimentel, A.S.G. Costa, M. Alvarez-Ortí, J.E. Pardo, M.B.P.P. Oliveira, Food Sci. Human Wellness **8**, 292 (2019)
10. L.H. Channaiah, M. Michael, J.C. Acuff, K. Lopez, R.K. Phebus, H. Thippareddi, G. Milliken, Int. J. Food Microbiol. **294**, 27 (2019)
11. S.M.T. Gharibzahedi, J. Ethnic Foods **5**, 105 (2018)
12. T. Ozdal, E. Capanoglu, F. Altay, Food Res. Int. **51**, 954 (2013)
13. M. Minekus, M. Alminger, P. Alvito, S. Ballance, T. Bohn, C. Bourlieu, F. Carrière, R. Boutrou, M. Corredig, D. Dupont, C. Dufour, L. Egger, M. Golding, S. Karakaya, B. Kirkhus, S. Le Feunteun, U. Lesmes, A. Macierzanka, A. Mackie, S. Marze, D.J. McClements, O. Ménard, I. Recio, C.N. Santos, R.P. Singh, G.E. Vegarud, M.S.J. Wickham, W. Weitschies, A. Brodkorb, Food Funct. **5**, 1113 (2014)
14. S. Kamiloglu, M. Tomas, T. Ozdal, E. Capanoglu, Trends Food Sci. Technol. **117**, 15 (2021)
15. A.H. Goli, M. Barzegar, M.A. Sahari, Food Chem. **92**, 521 (2005)
16. M. Pinelo, M. Rubilar, J. Sineiro, M.J. Núñez, Food Chem. **85**, 267 (2004)
17. M. del P. Garcia-Mendoza, F. A. Espinosa-Pardo, R. Savoire, C. Etchegoyen, C. Harscoat-Schiavo, and P. Subra-Paternault, Ind Crops Prod **167**, 113546 (2021).
18. A. Brodkorb, L. Egger, M. Alminger, P. Alvito, R. Assunção, S. Ballance, T. Bohn, C. Bourlieu-Lacanal, R. Boutrou, F. Carrière, A. Clemente, M. Corredig, D. Dupont, C. Dufour, C. Edwards, M. Golding, S. Karakaya, B. Kirkhus, S. Le Feunteun, U. Lesmes, A. Macierzanka, A.R. Mackie, C. Martins, S. Marze, D.J. McClements, O. Ménard, M. Minekus, R. Portmann, C.N. Santos, I. Souchon, R.P. Singh, G.E. Vegarud, M.S.J. Wickham, W. Weitschies, I. Recio, Nat. Protoc. **14**, 991 (2019)
19. S. Bakir, R.D. Hall, R.C.H. de Vos, R. Mumm, Ç. Kadakal, E. Capanoglu, Food Chem. **403**, 134123 (2023)
20. V. L. Singleton, R. Orthofer, and R. M. Lamuela-Raventós, in (1999), pp. 152–178.
21. A. Kumaran, R.J. Karunakaran, Food Chem. **97**, 109 (2006)
22. R. Apak, K. Güçlü, M. Özyürek, S.E. Karademir, J. Agric. Food Chem. **52**, 7970 (2004)
23. S. Wu, D. Shen, R. Wang, Q. Li, R. Mo, Y. Zheng, Y. Zhou, Y. Liu, Food Chem. **350**, 129217 (2021)
24. E. Capanoglu, S. Kamiloglu, S. Demirci Cekic, K. Sozgen Baskan, A. N. Avan, S. Uzunboy, and R. Apak, in (2021), pp. 1–66.
25. L.F. Călinoiu, D.C. Vodnar, Nutrients **10**, 1615 (2018)
26. P. Van Hung, Crit. Rev. Food Sci. Nutr. **56**, 25 (2016)
27. L. Yu, A.-L. Nanguet, T. Beta, Antioxidants **2**, 370 (2013)
28. V. Melini, F. Melini, R. Acquistucci, Antioxidants **9**, 343 (2020)
29. N. Ortega, A. Macià, M.-P. Romero, J. Reguant, M.-J. Motilva, Food Chem. **124**, 65 (2011)
30. G. Rocchetti, G. Chiodelli, G. Giuberti, L. Lucini, Food Chem. **245**, 633 (2018)
31. V. Goulas, A. Hadjisolomou, LWT **101**, 269 (2019)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.