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Date palm (*Phoenix dactylifera*) and enriched fresh goat cheese: (poly)phenol profile and stability after INFOGEST 2.0 *in vitro* digestion method

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ABSTRACT

Date palm fruit (*Phoenix dactylifera*) is a nutrient-dense food rich in (poly)phenols. This study evaluated the profile and stability of free and bound (poly)phenols in underutilized Confitera fresh dates and in fresh goat cheese fortified with 4 % and 8 % date paste, including their behavior during *in vitro* gastrointestinal digestion. A total of 45 (poly)phenols were identified in date paste, mainly hydroxycinnamic acids and flavonols. In fortified cheeses, 22 (poly)phenols were quantified, with flavonols showing higher retention (100 %) than hydroxycinnamic acids (54.0 %). *In vitro* digestion revealed high stability and increased bioaccessibility of several date-paste (poly)phenols, such as caffeoylshikimic acid (250 %) and chrysoeriol glycoside (160 %). In contrast, the dairy matrix markedly reduced the stability of soluble-free (poly)phenols in enriched cheese, where only four compounds remained detectable, with bioaccessibility values ranging 11–43 %. The insoluble-bound fraction retained most compounds, and new compounds appeared after digestion. The highest colon-available index in enriched cheese was observed for ferulic acid (1000 %). Overall, the study indicated that the food matrix plays a decisive role in modulating the release and stability, of (poly)phenols during digestion.

1. Introduction

Date palm fruit (*Phoenix dactylifera*) is a staple food in many regions of the world, especially in North Africa. It is considered a nutrient-dense food due to its richness in carbohydrates, including simple sugars (fructose, glucose, and sucrose), as well as dietary fiber, vitamins, and minerals (Muñoz-Bas et al., 2023). Interestingly, despite their high glucose content, dates have a relatively low glycemic index (Alfaro-Viquez et al., 2018). Consequently, their use as a natural sweetener and as an ingredient in food reformulation, such as dairy and pastry products, has increased substantially in recent years (Elkot et al., 2025; Pal et al., 2024; Ranasinghe et al., 2025; Sirisena et al., 2018). Dates are a valuable source of (poly)phenols, including flavonoid glycosides, and hydroxycinnamates, among others (AlFaris et al., 2021; Echegaray et al., 2020), which have been correlated with their antioxidant activity (AlFaris et al., 2021; Fernández-López et al., 2022).

Within plant cells, (poly)phenols occur in both soluble and insoluble forms. The soluble fraction is mainly localised in the vacuole, where (poly)phenols can exist in free form or conjugated with other molecules. In contrast, the insoluble fraction is associated with the cell wall, where (poly)phenols play a structural role by being covalently bound to components such as pectin, cellulose, hemicellulose, or proteins (Acosta-Estrada et al., 2014; Shahidi & Yeo, 2016; Yao et al., 2021) These compounds represent large proportion (20 %–60 % in vegetables, fruits, and legumes/seeds) compared to soluble forms (Acosta-Estrada et al., 2014; Shahidi & Yeo, 2016), however limited information about them are available due to the time-consumption extraction method compared to soluble-free (poly)phenols extraction.

The production and commercialization of fresh dates in the southeast of Spain (Elche, Alicante) have emerged as a promising economic activity. Due to climate change, date palm cultivation is finding exceptional climatic conditions in this region, contributing to local economic development (Fernández-López et al., 2022). Moreover, several processes have been developed to valorize date co-products (dates discarded from the fresh market due to size, color, or minor damage caused by insects or handling), leading to value-added products such as date

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paste, date powder, and date juice (Muñoz-Bas, Muñoz-Tebar, Viuda-Martos, et al., 2024). These ingredients have been applied as functional components in the development of fortified or enriched foods, including dairy products (Muñoz-Bas et al., 2024a; Muñoz-Tebar et al., 2024c) and meat products (Sánchez-Zapata et al., 2011). However, beyond product innovation, it is essential to investigate their behaviour during gastrointestinal digestion to assess the stability of their main phytochemical compounds such as (poly)phenols within different food matrices.

Both date seeds and date fruits have previously been subjected to *in vitro* digestion to evaluate the recovery and stability of their (poly)phenolic profile. Djaoudene et al. (2021) assessed lyophilized samples, while Hilary et al. (2020) also investigated the stability of seed date (poly)phenols incorporated into bread. In addition, the stability of (poly)phenols from various sources, such as pomegranate juice, cinnamon powder, microencapsulated grape pomace, and coffee, has been examined after digestion in dairy matrices, mainly yogurt. These studies have highlighted strong interactions between milk proteins and (poly)phenols, which in many cases contribute to the low recovery of (poly)phenols following digestion, reaching values below 40 % in coffee-fortified yogurt. However, to the best of our knowledge, information regarding the stability of soluble-free and insoluble-bound (poly)phenols in fresh dates, as well as their behaviour in fresh cheese, remains limited. Moreover, there is limited information available on studies that characterize the (poly)phenols profile in hybrid dairy products.

Therefore, this study aimed to quantify the soluble-free and insoluble-bound (poly)phenols in fresh date palm paste (Confitera vr.) (*Phoenix dactylifera*) and to investigate their recovery in fresh goat cheese. Furthermore, the bioaccessibility and colon-available fraction of free and bound (poly)phenols in both the date paste and the fortified fresh goat cheese.

2. Materials and methods

2.1. Reagents

Green tea catechin mix (G-016), pancreatin from porcine pancreas (P7545), pepsin from porcine gastric mucosa (P6887), and bile from bovine and ovine (B8381) were purchased from Merck (Darmstadt, Germany). Six monoglycosides mixture (pelargonidin 3-glucoside, cyanidin 3-glucoside, peonidin 3-glucoside, delphinidin 3-glucoside, petunidin 3-glucoside, and malvidin 3-glucoside), malvidin, and malvidin 3,5-diglucoside were purchased from Biolink Group-Polyphenols AS (Sandnes, Norway). The following individual (poly)phenol standard: 4-hydroxybenzoic acid, apigenin, apigenin 7-*O*-glucoside, caffeic acid, catechin, catechin-3-gallate, cinnamic acid, crypto chlorogenic acid, diosmetin-7-*O*-rutinoside (diosmin), diosmetin-7-*O*-neohesperidoside (neodiosmin) ellagic acid, epicatechin, eriodictyol-7-*O*-rutinoside (eriocitrin), ferulic acid, gallic acid, gallocatechin gallate, hesperetin 7-rhamnoglucoside (hesperidin), isorhamnetin-3-*O*-glucoside, kaempferol, luteolin, myricetin, naringenin 7-O-neohesperidoside (naringin), naringenin 7-*O*-rutinoside (narirutin), *p*-coumaric acid, isosakuranetin-7-*O*-neohesperidoside (poncirin), protocatechuic acid, quercetin, quercetin 3-β-d-glucoside, quercetin 3-*O*-rhamnoside (quercitrin), quercetin 3-*O*-rutinoside (rutin), rosmarinic acid, sinapic acid, syringic acid, vanillic acid, and vanillin, were purchased from Merck (Darmstadt, Germany) or EXTRASYNTHESE SAS (Z.I Lyon Nord, France). All other reagents were purchased from PanReac ApliChem (Barcelona, Spain).

2.2. Materials

Date paste (DP) was obtained from coproducts of fresh dates (*Phoenix dactylifera*, Confitera cv.) on the Tamar ripening stage followed the process described by Muñoz-Bas et al. (2024c). In brief, discarded date palm from Elche palm grove (Alicante, Spain) were pitted and minced. The main components of the date paste were moisture, sugars, and total dietary fiber, with values ranging from 48.0 to 48.5 g/100g, 31.0–31.5 g/100g, and 18.3–18.9 g/100g, respectively.

The obtained date paste was employed to enriched to 4 % and 8 % goat fresh cheese following the procedure previously described by Muñoz-Bas et al. (2024b). The three fresh cheese developed, control cheese (without date palm addition), fresh goat cheese with 4 % addition of date palm paste (DPC-4) and fresh goat cheese with 8 % addition of date palm paste (DPC-8) were made using goat milk that was collected from the farm of the Miguel Hernandez University (Orihuela, Alicante, Spain) and was pasteurized (72 °C/15 s) before using it.

2.3. (Poly)phenol extraction

(Poly)phenol extraction was performed in four different matrices: date palm paste (DP), fresh goat cheese control (CT), fresh goat cheese with 4 % addition of date palm paste (DPC-4) and fresh goat cheese with 8 % addition of date palm paste (DPC-8). Two complementary extraction methods were used to recover free-soluble (poly)phenols and the insoluble-bound compounds.

2.3.1. Soluble-free (poly)phenols

For the extraction of free (poly)phenols, the procedure described by Lucas-González et al. (2023) was followed with minor modifications. Briefly, 5 g of each sample was weighed and mixed with 50 mL methanol-water solution (80:20, v/v). The mixture was homogenized for 1 min using a T-25 Digital Ultraturrax (IKA Works, Spain) and subsequently centrifuged at 7000 g for 10 min at 4 °C. The supernatant was collected in a 250 mL flask. The extraction was repeated using 50 mL of an acetone-water solution (70:30, v/v). Both supernatants were combined and concentrated under reduced pressure using a rotary evaporation (Rotavapor®, Büchi, model R-200, Switzerland). The dry residue was reconstituted in 10 mL of distilled water, passed through a C18 cartridge (CHROMAFIX®) and eluted with formic acid:methanol for HPLC analysis (1:99, v/v).

2.3.2. Insoluble-bound (poly)phenols

For the extraction of insoluble-bound (poly)phenols, the pellet obtained after the extraction of free (poly)phenols was used, following the methodology described by (Mpofu et al., 2006) with the modification reported by Lucas-González et al. (2023). Briefly, the pellet was suspended in 40 mL of NaOH (4 mol/L) and stirred for 4 h in the dark using a rotary agitator (Intelli-Mixer RM-2M, ELMI, Latvia). Then, the pH was adjusted to 2.0 with HCl (6 mol/L) and the mixture was centrifuged at 10 000 g for 20 min at 4 °C. The resulting supernatant was transferred to separating funnel, mixed with 30 mL of ethyl acetate, shaken for 2 min and left to stand for 24 h. The aqueous phase was washed twice with 20 mL of ethyl acetate. The organic phase was filtered and subsequently evaporated in a rotary evaporator (Rotavapor®, Büchi, model R-200, Switzerland). Finally, the residue was reconstituted in 10 mL of water, purified through C18 solid-phase extraction cartridge (CHROMAFIX®), and eluted with formic acid: methanol for HPLC analysis (1:99, v/v).

2.4. Detection and identification of (poly)phenols

(Poly)phenol analysis was performed by High-Performance Liquid Chromatography (HPLC; Hewlett-Packard Series 1200) using a C18 column (Mediterranean Sea18, 25 × 0.4 cm, 5 μm particle size; Teknokroma, Barcelona, Spain). The mobile phases consisted of acetonitrile and formic acid:water (1:99, v/v), applied under gradient conditions as described by Genskowsky et al. (2016). Detection was monitored at 280, 325, 360, and 520 nm. Compounds were tentatively identified by comparing retention times and UV–Vis spectra with authentic standards (Supplementary Fig. 1); when standards were unavailable, identification was supported by literature data (Farag et al., 2014; Hilary et al., 2020). Quantification was based on calibration curves from available standards.

2.5. In vitro gastrointestinal digestion

In vitro digestion was performed following the INFOGEST 2.0 protocol (Brodkorb et al., 2019). Prior to digestion, samples were conditioned. For the date paste, a tomato paste-like consistency was obtained by mixing 2 g of date paste with 3 g of distilled water, and this mixture was used for digestion. Cheese samples (control and date-paste-enriched) were minced using a coffee mill. Digestion began by mixing 5 g of sample with 5 mL of simulated salivary fluid without α-amylase (1:1, w/v), followed by shaking at 70 rpm, at 37 °C for 2 min. Subsequently, 10 mL of simulated gastric solution (pepsin 2000 U/mL) was added, the pH was adjusted to 3.0 and samples were incubated for 2 h in a water bath orbital (37 °C and 70 rpm). To stop the gastric phase, the pH was adjusted to 7.0, and 20 mL of simulated intestinal fluids (pancreatin 100 U/mL trypsin; bile salts 10 mM) were added and incubation continued for another 2 h. After digestion, the samples were centrifuged at 7000 g for 10 min. The resulting supernatant was used to determine soluble-free (poly)phenols; it was filtered, passed through a C18 solid phase extraction cartridge (CHROMAFIX®), and resuspended in formic acid:methanol (1:99, v/v) for HPLC analysis. The pellet was used for extraction of insoluble-bound (poly)phenols as described on section 2.3.2.

2.6. (Poly)phenol stability and bioaccessibility after in vitro gastrointestinal digestion

The stability of (poly)phenols throughout cheese manufacture was evaluated by calculating the recovery index, defined as the ratio between the theoretical (poly)phenol content predicted from the formulation and the amount experimentally determined concentration in the final product. Moreover, the stability of (poly)phenols following *in vitro* gastrointestinal digestion was assessed through the bioaccessibility index and the colon-available index, calculated according to Equations (1) and (2) (Lucas-González et al., 2021).

$$\textit{Bioaccessibility index}\ (\%) = \frac{CSF}{TP_u}\ x\ 100 \qquad \text{(eq 1)}$$

Where,

CSF: Chyme soluble fraction (soluble-free (poly)phenols after intestinal digestion) (μg/g)

TPu: Total (poly)phenol content in the undigested sample, expressed either as soluble-free alone or as the sum of soluble-free and insoluble-bound fractions, depending on the (poly)phenol (μg/g). For the calculation of the total bioaccessibility of all (poly)phenols present in the samples, the sum of both fractions (soluble-free + insoluble-bound) was used.

$$\textit{Colon availible index}\ (\%) = \frac{BPi}{BP_u}\ x\ 100 \qquad \text{(eq 2)}$$

Where,

BPi: Insoluble-bound (poly)phenols after intestinal phase (μg/g)

BPu: Insoluble-bound (poly)phenols on undigested samples (μg/g)

2.7. Statistical analysis

All analyses were performed in triplicate. Statistical treatment of the data was conducted using SPSS Statistics v.26, (IBM Corp., Armonk, NY, USA). A one-way ANOVA (95 % confidence level) was applied to assess significant differences among samples, followed by Tukey's post-hoc test to determine significant differences ($P < 0.05$).

3. Results and discussion

3.1. (Poly)phenol profile on date palm paste

A total of fifty (poly)phenols were detected in both the free and bound fractions Confitera date paste (Table 1). Of these, thirteen compounds were unequivocally confirmed by comparison with pure standards. The remaining compounds were tentatively identified by comparing their retention times and UV–Vis absorption spectra with those available standards and with data reported in the literature (Table 1), except for compounds no.10 and no. 34 (Table 1), which could not be identified. Each subfamily of (poly)phenols exhibits a characteristic absorbance profile and elutes according to decreasing polarity. Typically, phenolic acids and flavonoid diglucosides elute first, followed by monoglucosides, acylated monoglucosides, and finally free aglycones (Farag et al., 2014) (Supplementary Figs. 1 and 2).

The greatest diversity of compounds was observed in the soluble-free fraction, in which thirty compounds were detected. Hydroxycinnamic acids and their derivatives were the most abundant group (ten compounds), followed by flavonols (nine compounds), and flavanones (six compounds). In contrast, the insoluble-bound fraction was dominated by flavan-3-ols (ten compounds). Only quercetin and ferulic acid were detected in both fractions. Among the predominant soluble-free compounds, chrysoeriol glycoside 1 exhibited the highest concentration, followed by caffeic acid and caffeoylshikimic acid 1 (Table 2).

Among the hydroxycinnamic acids detected, caffeic, ferulic and chlorogenic acids were confirmed using analytical standards. The remaining compounds were tentatively identified as caffeic acid or *p*-coumaric acid conjugates. Compounds exhibiting a lower λ_{max} than the aglycones (318–320 nm, instead 324–328 nm) and eluting earlier were considered glycosylated derivatives. Previous studies have also reported a wide diversity of hydroxycinnamic acids in dates, including caffeoylshikimic acid glycosides, and glycosides of caffeic and ferulic acids in Deglet Nour and Medjool cultivars (Hammouda et al., 2013; Khallouki et al., 2018; Mansouri et al., 2005; Alfaro-Víquez et al., 2018).

Regarding flavonoids, glycosylated and methylated derivatives of quercetin and luteolin were the predominant compounds in Confitera date paste. In particular, rutin, quercetin-β-D-glucoside, quercitrin, isorhamnetin-3-*O*-glucoside, diometin and chrysoeriol were confirmed by comparison with analytical standards. These findings are consistent with previous studies, which have reported a high diversity of glycosylated flavonoids in date fruit. Farag et al. (2014) identified 20 flavonoids in several Egyptian cultivars, mainly flavonols and flavones. While Nematallah et al. (2018) detected nineteen flavonoids in Ajwa dates at the Tamr stage. In Mature Deglet Noor dates, 13 glycosides of luteolin, quercetin, and apigenin have also been reported. Notably, some authors have reported the unusual occurrence of flavonoid sulfates in dates, a feature rarely described in foods (Hong et al., 2006).

The highest proportion of (poly)phenols was found in the insoluble-bound fraction, which accounted for approximately 87 % of the total (poly)phenol content, mainly due to the contribution of proanthocyanidins 4 and 5. Similar findings were reported by Hammouda et al. (2013), who observed that procyanidin polymers represented about 80 % of the total (poly)phenols in Deglet Nour dates at the Tamar stage. In the present work, the total soluble-free (poly)phenol content in Confitera date paste was near 8.5 mg/100 g fw, a value around seven times lower than reported by Khallouki et al. (2018) for fully ripe Medjool dates at the Tamar stage (61.3 mg/100 g). Other studies have reported values ranging from 10.9 to 42.3 mg/100 g dw in pulp (without peel) of 17 Moroccan cultivars at the Tamar stage (Alahyane et al., 2019), and from 25.1 to 33.9 mg/100g dw in whole Boufeggous and Mejhoul dates (Noutfia et al., 2025). These discrepancies can be largely attributed to differences in postharvest processing. Specifically, Confitera date analyzed in the present study was not subjected to sun-drying, a common preservation practice in date fruits (Jaouhari et al., 2024). Consequently, the paste retained a moisture content of approximately 48 %,

Table 1
Specification to (poly)phenol compounds detected in date palm fruit paste cv. Confitera.

No.	rt (min)	Fr.	λmax (nm)	Tentative identification	Standard use to quantified
1	7.9	B	236 280	Flavan-3-ol	Catechin
2	11.2	F	242 294sh 318	Hydroxybenzoic derivative 1	Vanillin
3	11.8	F	244 292sh 314	Caffeic acid glycoside	Caffeic acid
4	12.1	F	242 290sh 320	Caffeoylshikimic acid glycoside	Chl
5	12.7	F	242 292 318	Hydroxybenzoic derivative 2	Vanillin
6	12.7	B	236 274 406 474	Anthocyanin derivative 1	Pel-3-glu
7	12.9	F	242 290sh 322	Caffeoylshikimic acid 1	Chl
8	13.7	B	236 280 310	Vanillin glycoside 1	Vanillin
9	14.7	F	254 348	Quercetin triglycoside	Rutin
10	14.8	B	236 320 458	Unknow	–
11	14.9	F	246 292sh 326	Chlorogenic acid*	Chl
12	15.2	B	236 280 310	Vanillin glycoside 2	Vanillin
13	15.3	B	236 280	Catechin *	Catechin
14	15.6	B	236 280	Proantochyanidin 1	PAC B2
15	17.3	F	266 338	Apigenin glycoside	Api-7-glu
16	17.3	F	244 284sh 324	Caffeoylshikimic acid 2	Chl
17	17.6	F	242 290sh 324	Caffeoylshikimic acid 3	Chl
18	17.8	B	236 280	Proanthocyanindin 2	PAC B2
19	17.9	B	236 280	Epicatechin*	Epicatechin
20	18.1	F	242 300sh 326	Caffeic acid*	Caffeic acid
21	18.2	B	236 274 414 474	Anthocyanin derivative 2	Pel-3-glu
22	18.4	B	236 280	Proanthocyanidin 3	PAC B2
23	18.9	F	244 sh286 322	Caffeoylshikimic acid 4	Chl
24	19.4	F	244 sh286 324	Caffeoylshikimic acid 5	Chl
25	19.6	B	240 280	Proantochyanidin 4	PAC B2
26	20.0	F	254 358	Quercetin diglycoside 1	Rutin
27	20.7	F	258 360	Quercetin diglycoside 2	Rutin
28	21.0	B	238 272 416 472	Anthocyanidin derivative	Pel-3-glu
29	21.1	B	236 278	Proantochyanidin 5	PAC B2
30	22.1	F	256 358	Quercetin diglycosilate 3	Rutin
31	22.3	F	256 358	Quercetin-3-rutinoside (Rutin)*	Rutin
32	22.5	B	236 292sh 330	Flavanone hexoside	Naringin
33	23.7	F	256 264sh 362	Quercetin-3-β-D-glucoside*	Que-3-glu
34	24.1	B	238 270 332 482	Unknow	–
35	24.1	B	240 278	Catechin-3-gallate*	Cat-3-gal
36	24.6	F/B	246 286sh 324	Ferulic acid*	Ferulic acid
37	24.9	F	256 358	Quercetin glycosilate 1	Que-3-glu
38	25.4	F	256 358	Quercetin glycosilate 2	Que-3-glu
39	25.9	F	264 354	Isorhamnetin-3-*O*-glucoside*	Iso-3-glu
40	26.0	F	254 266 350	Diosmetin-7-*O*-rutinoside (Diosmin)*	Diosmin
41	26.3	F	254 356	Quercetin-3-rhamnoside (Quercitrin)*	Quercitrin
42	26.9	B	236 276 452	Anthocyanin derivative 4	Pel-3-glu
43	28.1	F	254 362	Isorhamnetin glycoside	Iso-3-glu
44	28.7	F	252 268 348	Chrysoeriol glycoside 1	Diosmin
45	29.4	F	252 268 346	Chrysoeriol glycoside 2	Diosmin
46	32.9	B	242 300sh 326	Caffeic acid derivative	Caffeic acid
47	33.8	F/B	256 370	Quercetin*	Quercetin[a]
48	38.0	F	252 268 348	Chrysoeriol*	Chrysoeriol
49	38.5	F	253 266 348	Luteolin mutilated	Diosmin
50	38.7	B	266 366	Kaempferol*	Kaempferol

rt: retention time; Fr.: Fraction; B: Insoluble-bound; F: Soluble-free.
Chl: Chlorogenic acid; Proantochyanidin B2: PAC B2; Apigenin-7-glucoside: Api-7-glu; Isorhamnetin-3-*O*-glucoside: Iso-3-glu; Quercetin-3-β-D-glucoside: Que-3-glu; Pelargonidin 3-*O*-β-glucopyranoside: Pel-3-glu; Cat-3-gal: Catechin-3-gallate.
[a] Compound confirmed by standard.

compared with the ~17 % reported for sun-dried Medjool dates (Eid et al., 2013).

3.2. (Poly)phenol profile on cheese goat

As expected, no (poly)phenols were detected in the control goat cheese (prepared without date paste). In contrast, a total of 22 compounds were quantified in the DPC-4 and DPC-8 formulations, including seventeen in the soluble-free fraction forms and five in the insoluble-bound fractions. (Table 3). Consistent with the profile of the date paste, chrysoeriol glycoside 1, caffeic acid, and caffeoylshikimic acid 1 were the predominant soluble (poly)phenols in both date-paste-enriched fresh goat cheeses (Table 3).

The recovery of total soluble-free and insoluble-bound (poly)phenols in both DPC-4 and DPC-8 was approximately 59–60 % and 11–19 %, respectively (Table 3). Flavonols were retained in the cheese matrix to a greater extent than flavones and hydroxycinnamic acids, which showed retention around 50 %. As a result, the enriched cheeses exhibited a higher relative proportion of flavonols than the original date paste, where soluble hydroxycinnamic acids were the predominant group. Mangiapelo et al. (2025) similarly reported high stability of glycosylated quercetin but a reduction of chlorogenic acid, attributed to enzymatic hydrolysis by cinnamoyl esterase converting it to caffeic acid. Additionally, chlorogenic acid has been shown to form non-covalent interactions with β-lactoglobulin, a major whey protein (Ren et al., 2023), which may further influence its distribution between curd and whey. Other studies reported reductions in hydroxycinnamic acids in dairy milk, such as Helal and Tagliazucchi (2018), who observed decreased hydroxycinnamic acid levels in coffee-fortified yogurt during storage. These differences may be attributed to variations in solubility and the affinity of individual (poly)phenols to interact with milk proteins. Furthermore, the addition of date palm to goat cheese fresh decreased the cheese yield in a concentration dependent manner (Muñoz-Bas et al., 2024b). Indicating that date palm affects curd formation and part of date palm added was lost on drained curd.

Table 2
Individual (poly)phenol content and total amount of compounds (μg/g f.w) from undigested and digested date palm paste variety Confitera at the Tamar stage.

Subfamily	Compounds		Undigested	Digested
Hydroxybenzoic acid derivatives	Hydroxybenzoic derivative 1	F	0.9 ± 0.1[a]	0.8 ± 0.0[a]
	Hydroxybenzoic derivative 2	F	2.5 ± 0.2[a]	2.7 ± 0.1[a]
	Vanillin glycoside 1	B	0.5 ± 0.1[b]	3.9 ± 0.4[a]
	Vanillin glycoside 2	B	3.1 ± 0.4[b]	22.7 ± 2.8[a]
Hydroxycinnamic acids and derivatives	Caffeic acid glycoside	F	1.2 ± 0.1[a]	0.7 ± 0.1[b]
	Caffeoylshikimic acid glycoside	F	7.2 ± 0.8[a]	7.3 ± 0.9[a]
	Caffeoylshikimic acid 1	F	8.5 ± 0.6[a]	5.0 ± 0.2[b]
	Chlorogenic acid	F	3.2 ± 0.3[a]	2.7 ± 0.2[a]
	Caffeoylshikimic acid 2	F	1.1 ± 0.1	nd
	Caffeoylshikimic acid 3	F	3.0 ± 0.3	nd
	Caffeic acid	F	8.8 ± 0.9[b]	11.7 ± 0.5[a]
	Caffeoylshikimic acid 4	F	3.5 ± 0.2[b]	4.3 ± 0.3[a]
	Caffeoylshikimic acid 5	F	3.6 ± 0.3[b]	9.8 ± 1.1[a]
	Ferulic acid	F	0.4 ± 0.0[b]	0.6 ± 0.1[a]
		B	5.9 ± 0.5[b]	15.4 ± 0.4[a]
	Caffeic acid derivative	B	nd	1.2 ± 0.1
Flavonols	Quercetin triglycoside	F	nd	0.6 ± 0.1
	Quercetin diglycoside 1	F	nd	0.6 ± 0.0
	Quercetin diglycoside 2	F	nd	0.4 ± 0.0
	Quercetin diglycoside 3	F	1.4 ± 0.2[b]	1.6 ± 0.1[a]
	Quercetin-3-rutinoside	F	1.7 ± 0.1[a]	1.5 ± 0.0[a]
	Quercetin-3-β-D-glucoside	F	1.9 ± 0.2[a]	1.2 ± 0.2[b]
	Quercetin glycoside 1	F	2.1 ± 0.0[a]	2.3 ± 0.3[a]
	Quercetin glycoside 2	F	3.6 ± 0.3[a]	2.8 ± 0.3[a]
	Isorhamnetin-3-*O*-glucoside	F	0.6 ± 0.1[a]	0.3 ± 0.1[b]
	Quercetin-3-rhamnoside	F	1.3 ± 0.1[a]	0.9 ± 0.3[a]
	Isorhamnetin glycoside	F	1.6 ± 0.2[a]	0.3 ± 0.1[b]
	Quercetin	F	0.6 ± 0.1	nd
		B	1.2 ± 0.3[a]	1.5 ± 0.3[a]
	Kaempferol	B	nd	0.2 ± 0.0
Flavones	Apigenin glycoside	F	1.1 ± 0.1[a]	1.0 ± 0.1[a]
	Diosmetin 7-*O*-rutinoside	F	4.4 ± 0.3[a]	2.3 ± 0.2[b]
	Chrysoeriol glycoside 1	F	16.6 ± 1.2[a]	4.6 ± 0.7[b]
	Chrysoeriol glycoside 2	F	1.4 ± 0.0[b]	2.3 ± 0.5[a]
	Luteolin metilated	F	1.6 ± 0.1	nd
	Chrysoeriol	F	2.8 ± 0.3	nd
Flavan-3-ols	Flavan-3-ol derivative	B	11.4 ± 3.1[b]	40.7 ± 5.4[a]
	Catechin	B	35.3 ± 2.3[a]	21.8 ± 5.7[b]
	Proantocyanidin 1	B	14.9 ± 2.5[a]	16.6 ± 0.6[a]
	Proanthocyanidin 2	B	19.0 ± 1.9[a]	12.4 ± 0.3[b]
	Proanthocyanidin 3	B	19.6 ± 3.5	nd
	Epicatechin	B	10.8 ± 0.7[b]	34.9 ± 2.0[a]
	Proantochyanidin 4	B	61.8 ± 5.2[a]	31.5 ± 3.0[b]
	Proantochyanidin 5	B	252 ± 79.2	nd
	Catechin-3-gallate	B	17.4 ± 2.1	nd
Other flavonoids	Anthocyanin derivative 1	B	nd	11.0 ± 0.5
	Anthocyanin derivative 2	B	0.3 ± 0.0[b]	2.1 ± 0.1[a]
	Anthocyanin derivative 3	B	1.4 ± 0.3[b]	38.1 ± 0.3[a]
	Anthocyanin derivative 4	B	nd	1.9 ± 0.4
	Flavanone	B	13.9 ± 1.2[b]	112 ± 8.1[a]
	Total, (poly)phenols	F	86.9 ± 2.1[a]	68.8 ± 1.6[b]
		B	468 ± 85.1[a]	367.4 ± 18.2[a]
	Total, Hydroxycinnamic acids	F	40.9 ± 2.5[a]	42.8 ± 1.5[a]
		B	5.9 ± 0.5[b]	16.6 ± 0.4[a]
	Total, Hydroxybenzoic acids	F	3.5 ± 0.3[a]	3.5 ± 0.1[a]
		B	3.4 ± 0.5[b]	26.6 ± 2.9[a]
	Total, Flavonols	F	14.7 ± 1.2[a]	12.4 ± 1.4[a]
		B	1.2 ± 0.3[a]	1.6 ± 0.2[a]
	Total, Flavones	F	27.9 ± 1.4[a]	10.1 ± 1.1[b]
	Total, Flavan-3-ols	B	442 ± 83.3[a]	158 ± 11.9[b]

nd: Not detected. Different letters in the same row indicated significant differences according to Tuckey's post hoc test ($p < 0.05$).

Regarding the recovery index of individual (poly)phenols, the most remarkable value was observed for ferulic acid, with a recovery index exceeding 800 % in both enriched cheeses (Table 2). This phenomenon could be attributed to the release of conjugated ferulic acid during cheese manufacture, likely resulting from its association with other macronutrients, such as proteins. Indeed, in date seeds, caffeic acid, ferulic acid, p-coumaric acid, and quercetin have been reported at significantly higher concentrations in soluble-conjugated fractions than in their soluble-free forms (Lucas-González et al., 2023). Furthermore, the mediated enzymatic hydrolysis can also release ferulic acid that found conjugated with caffeic acid or other quinic acid derivatives (Mangiapelo et al., 2025).

Many authors who enriched dairy products with plant extracts have pointed out that differences in recovery are related to the varying binding affinities of individual polyphenols to milk proteins. For example, on cinnamon extract-fortified yogurt the recovery of kaempferol was 21 % while the recovery of quercetin was 55 % (Helal & Tagliazucchi, 2018). Trigueros et al. (2014) reported that, among phenolic compounds from pomegranate juice present on yogurt, ellagic acid and delphinidin-3,5-*O*-diglucoside exhibited the lowest affinity for binding to milk proteins. Furthermore, they highlighted that, in general, monoglucosides of flavonoids show stronger binding affinities to milk proteins than their polyglucoside forms. This phenomenon could explain the differences in recovery index observed in the present study among flavanols, such as quercetin-3-β-D-glucoside, isorhamnetin glycoside,

Table 3
(Poly)phenol profile (μg/g f.w) of undigested and digested enriched date palm-goat fresh cheeses and the theorical retention index after manufacturing process.

		Undigested DPC-4	Digested DPC-4	Undigested DPC-8	Digested DPC-8	RI (%) DPC-4	RI (%) DPC-8
Hydroxybenzoic derivative 1	F	2.2 ± 0.2^{b}	nd	5.9 ± 0.4^{a}	nd	59.8 ± 5.9^{a}	81.6 ± 6.0 ^{b}
Hydroxybenzoic derivative 2	F	4.2 ± 0.5^{b}	nd	8.5 ± 0.4^{a}	nd	42.5 ± 4.9^{a}	43.0 ± 2.1^{a}
Vanillin glycoside 1	B	4.5 ± 0.3^{c}	18.9 ± 2.7^{b}	4.9 ± 0.9^{c}	30.3 ± 2.9^{a}	219 ± 16.0^{a}	120.2 ± 22.7^{b}
Vanillin glycoside 2	B	33.6 ± 10.4^{c}	103 ± 3.6^{b}	32.4 ± 14.9^{c}	241.3 ± 3.5^{a}	274 ± 84.5^{a}	132 ± 60.6^{a}
Caffeoylshikimic acid glycoside	F	17.4 ± 2.1^{b}	3.5 ± 0.1^{c}	36.0 ± 3.2^{a}	4.0 ± 0.1^{c}	60.6 ± 7.3^{a}	62.8 ± 5.6^{a}
Chlorogenic acid	F	2.9 ± 0.7^{b}	nd	10.3 ± 0.0^{a}	nd	22.9 ± 5.4^{b}	40.1 ± 0.1^{a}
Caffeic acid	F	32.9 ± 0.4^{b}	16.0 ± 0.2^{c}	54.5 ± 2.8^{a}	17.5 ± 0.2^{c}	93.7 ± 1.1^{a}	77.6 ± 4.0^{b}
Caffeoylshikimic acid 5	F	19.5 ± 4.0^{b}	4.7 ± 0.5^{c}	49.3 ± 6.6^{a}	10.5 ± 0.7^{c}	134 ± 27.6^{a}	170 ± 22.8^{a}
Ferulic acid	F	16.3 ± 2.9^{b}	nd	27.2 ± 0.1^{a}	nd	1064 ± 192.8^{a}	892 ± 2.4^{a}
	B	5.4 ± 0.4^{c}	55.8 ± 3.3^{b}	10.5 ± 0.1^{c}	119 ± 3.6^{a}	22.9 ± 1.6^{a}	22.5 ± 0.2^{a}
Quercetin diglycoside 3	F	8.1 ± 0.9^{b}	nd	15.7 ± 1.7^{a}	nd	141.7 ± 15.7^{a}	137 ± 15.1^{a}
Quercetin-3-rutinoside (Rutin)	F	9.2 ± 1.8^{b}	nd	15.4 ± 1.5^{a}	nd	140 ± 27.9^{a}	116.4 ± 11.4^{a}
Quercetin-3-β-D-glucoside	F	6.3 ± 0.2^{a}	nd	9.6 ± 2.3^{a}	nd	82.7 ± 3.0^{a}	63.7 ± 15.0^{a}
Quercetin glycoside 1	F	12.9 ± 1.9^{b}	3.5 ± 0.1^{c}	24.3 ± 1.5^{a}	4.9 ± 0.2^{c}	156 ± 23.2^{a}	147 ± 9.2^{a}
Quercetin glycoside 2	F	16.7 ± 3.6^{b}	nd	29.9 ± 0.9^{a}	nd	116 ± 24.7^{a}	104 ± 3.3^{a}
Quercetin-3-rhamnoside (Quercitrin)	F	4.9 ± 0.4^{b}	nd	8.5 ± 0.3^{a}	nd	97.5 ± 7.3^{a}	84.6 ± 3.4^{a}
Isorhamnetin glycoside	F	2.8 ± 0.2^{b}	nd	5.7 ± 1.1^{a}	nd	43.4 ± 3.1^{a}	45.1 ± 8.4^{a}
Apigenin glycoside	F	4.0 ± 0.3^{b}	nd	7.9 ± 0.5^{a}	nd	88.3 ± 7.5^{a}	87.6 ± 5.7^{a}
Diosmetin 7-*O*-rutinoside (Diosmin)	F	10.7 ± 0.8^{b}	nd	25.7 ± 0.5^{a}	nd	61.0 ± 4.5^{b}	73.3 ± 1.5^{a}
Chrysoeriol glycoside 1	F	34.8 ± 5.3^{b}	nd	70.2 ± 8.7^{a}	nd	52.3 ± 7.9^{a}	52.8 ± 6.1^{a}
Flavanone	B	nd	870 ± 8.9^{b}	nd	1151 ± 70.5^{a}	–	–
Proantochyanidin 4	B	252 ± 15.9^{a}	nd	285 ± 9.6^{a}	nd	102 ± 6.4^{a}	57.5 ± 1.9^{b}
Anthocyanin derivative 1	B	nd	tr	nd	tr	–	–
Anthocyanin derivative 3	B	21.3 ± 0.1^{a}	65.6 ± 14.8^{a}	30.2 ± 6.4^{a}	98.2 ± 50.7^{a}	374 ± 2.2^{a}	264 ± 55.9^{a}
Anthocyanin derivative 4	B	nd	38.3 ± 27.1	nd	40.1 ± 0.7	–	–
Total (poly)phenols	F	206 ± 24.6^{b}	27.7 ± 0.6^{c}	405 ± 23^{a}	36.9 ± 1.0^{c}	59.2 ± 7.1^{a}	58.2 ± 3.4^{a}
	B	316 ± 10.7^{c}	1220 ± 64.1^{b}	363 ± 12.3^{c}	1700 ± 32.7^{a}	16.9 ± 0.6^{a}	9.7 ± 0.3^{b}
Total Hydroxycinnamic acids	F	88.9 ± 9.5^{b}	24.2 ± 0.6^{c}	177 ± 10.7^{a}	32. ± 0.8^{c}	54.4 ± 5.8^{a}	54.2 ± 3.3^{a}
	B	5.4 ± 0.4^{c}	55.8 ± 3.3^{b}	10.5 ± 0.1^{c}	119 ± 3.6^{a}	22.9 ± 1.6^{a}	22.5 ± 0.2^{a}
Total Hydroxybenzoic acids	F	6.4 ± 0.6^{b}	nd	14.4 ± 0.7^{a}	nd	47.1 ± 4.7^{a}	53.3 ± 2.6^{a}
	B	38.0 ± 10.0^{c}	121.7 ± 5.9^{b}	37.3 ± 15.6^{c}	272 ± 6.0^{a}	266 ± 70.2^{a}	131 ± 54.7^{a}
Total Flavonols	F	60.9 ± 8.4^{b}	3.5 ± 0.1^{c}	109 ± 7.7^{a}	4.9 ± 0.2^{c}	103.4 ± 14.2^{a}	92.7 ± 6.5^{a}
Total Flavones	F	49.5 ± 6.4^{b}	nd	104 ± 8.3^{a}	nd	44.3 ± 5.7^{a}	46.5 ± 3.7^{a}
Total Flavan-3-ols	B	252 ± 15.9^{a}	nd	285 ± 9.6^{a}	nd	14.2 ± 0.9^{a}	8.1 ± 0.3^{b}

Nd: not detected; tr: traces; DPC-4: fresh goat cheese with 4 % addition of date palm paste; DPC-8: fresh goat cheese with we8% addition of date palm paste; RI: Retention index; F: Soluble-free fraction: B: Insoluble-bound fraction.
Regarding undigested and digested samples or recovery index values different letters in the same row indicated significant differences according to Tuckey's post hoc test ($p < 0.05$).

and quercetin-3-rutinoside (Table 2).

In the insoluble-bound fraction, only proanthocyanidin 4 was detected among the nine flavan-3-ols in date paste. In contrast, two vanillin derivatives—originally present in smaller amounts than catechin and other flavan-3-ols—were found in the enriched cheese, along with ferulic acid and anthocyanin derivatives. The strong binding affinity of catechin and epicatechin with milk protein have been previously reported on mixture to milk and chocolate and tea and milk (Oliveira et al., 2015). Similar losses of insoluble-bound flavan-3-ols have been previously reported in other food matrices; for example, in pork liver pâté enriched with persimmon flour, only one of ten flavan-3-ols from the flour was detected in the enriched product (Lucas-González et al., 2021).

3.3. Stability of (poly)phenols from date palm paste after in vitro gastrointestinal digestion

The (poly)phenol profile of date palm underwent noticeable modifications following the gastrointestinal digestion process. Of the 27 soluble (poly)phenols detected in undigested date palm, five—caffeoylshikimic acids 2 and 3, quercetin, methylated luteolin, and chrysoeriol—, were no longer detected, likely due to their initial low concentration. Conversely, certain flavonols, including quercetin triglycoside and quercetin diglycosides 1 and 3, were only detected after *in vitro* digestion, indicating that the digestive process facilitated their release.

A similar trend was observed in the insoluble-bound fraction. Proanthocyanidins 3 and 5, along with catechin-3-gallate, were no longer detected after digestion. Instead, new compounds emerged during the *in vitro* digestion process, including a hydroxycinnamic acid derivative, kaempferol, and two anthocyanin derivatives.

Nevertheless, aside from the compounds that disappeared after digestion, (poly)phenols in date palm paste, generally exhibited high stability throughout the *in vitro* digestion process. Most compounds, such as caffeoylshikimic acid glycoside, chlorogenic acid, quercetin-3-rutinoside, quercetin-3-rhamnoside, and apigenin glycoside, showed no significant changes in concentration before and after digestion ($p > 0.05$). In contrast, some soluble compounds, including caffeic acid, quercetin diglycoside 3, caffeoylshikimic acids 4 and 5, and chrysoeriol glycoside 2, were detected at higher concentrations after digestion ($p < 0.05$). Certain insoluble-bound compounds, such as ferulic acid, epicatechin, flavanone and anthocyanin 1 and 4, were also detected at significantly higher levels than in undigested samples, ($p < 0.05$), suggesting enhanced release during digestion. Conversely, some soluble-free compounds decreased after digestion, as expected. Notably, chrysoeriol glycoside 1 and caffeoylshikimic acid 1, which were predominant in undigested samples, showed a marked and significant decrease after *in vitro* digestion ($p < 0.05$).

These findings are consistent with earlier studies on date fruit and seeds. Djaoudene et al. (2021) evaluated freeze-dried extracts of fruit pulp and seeds from eight Algerian date cultivars and found that *in vitro* digestion reduced pulp flavonols but increased caffeic acid, while seed extracts showed marked increases in phenolic acids and flavonoids across all cultivars. Likewise, Kamal et al. (2023) analyzed digested samples from four date varieties (Safawi, Khalas, Khudri, and Booman), and detected rutin, caffeic acid, and 4-hydroxybenzoic only after digestion. They also reported substantial increases in 1,2-dihydroxybenzoic and reductions in catechin and *p*-coumaric acid during the intestinal

phase in specific varieties. Overall, these studies show that the stability of polyphenols in date pulp and seed extracts is strongly affected by digestion, with outcomes depending on compound type and cultivar.

The different patterns in (poly)phenol stability can be explained by several interconnected factors. First, the increase in soluble-free (poly) phenols may result from the presence of soluble-conjugate forms (esterified, etherified or glycosylated) that were not extracted initially methodology but became released into the digestive medium through enzymatic hydrolysis. Indeed, in date seed, caffeic acid, ferulic acid, *p*-coumaric acid, and quercetin have been reported at significantly higher concentrations in soluble-conjugated fractions than in their soluble-free forms ($p < 0.05$) (Lucas-González et al., 2023). Similar trends have been observed for caffeic acid and chlorogenic acid in calafate (*Berberis microphylla*) byproducts, and for quercetin and rutin in araticum (*Annona crassiflora* Mart.), where esterified forms predominate (Arruda et al., 2018; Concepción-Alvarez et al., 2025). Second, the protective effect of the food matrix must be taken into account. Date palm fruit paste is a minimally processed product rich in dietary fiber and sugars, which may help safeguard (poly)phenols during gastrointestinal transit. Peters et al. (2010) used both *in vitro* and *in vivo* approaches, to show that sucrose can interfere with the binding of flavan-3-ols to other green tea components, such as caffeine, thereby enhancing catechin solubility and improving their bioaccessibility. Moreover, dietary fiber may physically entrap soluble (poly)phenols, which helps to stabilize (poly) phenols throughout digestion (Viuda-Martos et al., 2018). Finally, differences in (poly)phenol stability under alkaline intestinal conditions, along with potential interactions with bile salts, may further explain the compound-specific variability observed in this study (Lucas-González et al., 2018).

3.4. (Poly)phenols stability after in vitro gastrointestinal digestion of date palm paste–enriched fresh goat cheese

As observed for date palm paste alone, the (poly)phenolic profile of the enriched date palm paste–fresh goat cheese changed markedly after *in vitro* gastrointestinal digestion (Table 3). Of the seventeen soluble (poly)phenols present in the undigested P4 and P8 samples, only four were detected post-digestion: caffeic acid, caffeoylshikimic acid glycoside, caffeoylshikimic acid 5, and quercetin glycoside 1. All of these showed a significant decrease in their concentration after digestion compared with undigested sample ($p < 0.05$). Notably, chrysoeriol glycoside 1, the predominant soluble-free flavonoid in the undigested enriched date palm paste–fresh goat cheeses, was no longer detectable after digestion. This trend mirrors that observed in date paste, where chrysoeriol 1 dramatically decreased after digestion, and underscores the marked instability of this compound during both cheese manufacturing and *in vitro* digestion.

In the insoluble-bound fractions of the enriched date palm paste–-fresh goat cheeses, most (poly)phenols were present at significantly higher concentrations after digestion than in the undigested samples ($p < 0.05$), except for proanthocyanidin 4, which disappeared during the intestinal phase. Additionally, three new compounds, a flavone, and anthocyanin derivatives 1 and 4—were detected in both digested cheeses but were absent in the undigested samples (Table 3).

After gastrointestinal digestion, the only notable differences in (poly) phenol concentrations between the two enriched date palm paste–fresh goat cheeses (DPC-4 and DPC-8) were found in the insoluble-bound phenolic acids. DPC-8 showed significantly higher levels of these compounds. All other soluble and insoluble-bound phenolics were present at comparable concentrations in both cheeses without statistically significant difference ($p > 0.05$).

Comparable studies have examined enriched date seeds extract yogurt and seed extract-enriched bread subjected to *in vitro* gastrointestinal digestion. For the enriched bread, the findings aligned with those of the present study: (poly)phenol levels declined after digestion, and neither flavonols nor flavones were detected. In contrast, enriched yogurt demonstrated high (poly)phenols stability after the intestinal phase (Hilary et al., 2020). This discrepancy may be related to the fact that flavan-3-ols were the only (poly)phenolic compounds detected in yogurt, and these may exhibit different stability profiles compared with flavones and flavonols, which were the only flavonoids detected in the soluble-free fraction of the enriched date paste cheese. López-Astorga et al. (2025) added microencapsulated grape pomace extracts to Greek-style yogurt and observed less stability of phenolic acids than flavonoids. In line with the present study, López-Astorga et al. (2025) also highlighted that the nature of the (poly)phenols strongly influences their release from the food matrix and their stability during digestion.

3.5. Bioaccessibility and colon available index of date palm paste and enriched-goat fresh cheese

The bioaccessibility of (poly)phenols refers to the proportion of compounds that are released from the food matrix during digestion and become for transformation and absorption into the bloodstream. In contrast, the colon available index represents the fraction of (poly) phenols that remain bound to the food matrix and reach the colon, where they can be metabolized by the gut microbiota (Lucas-González et al., 2021).

Fig. 1 presents the bioaccessibility and colon-available index of the total (poly)phenol content in date palm paste, DPC-4, and DPC-8. Date palm paste exhibited the highest (poly)phenol bioaccessibility index ($p < 0.05$), whereas DPC-8 showed the highest colon-available index ($p < 0.05$). The low total (poly)phenol bioaccessibility of date palm paste contrasts with the high bioaccessibility values observed for several soluble-free individual (poly)phenols, which ranged from approximately 50–260 % (Fig. 2). This discrepancy arises because insoluble bound (poly)phenols represented the largest fraction in the date palm paste and were not released into the chyme solution during *in vitro* gastrointestinal digestion.

These results highlight the strong influence of the food matrix on the bioaccessibility and colon available index of (poly)phenols. The complex cheese matrix drastically reduced the release or stability of (poly)phenols during gastrointestinal digestion. In contrast, when date paste was digested alone, its main (poly)phenols showed high stability and bioaccessibility (Fig. 2). Similar findings have been previously reported, where the bioaccessibility of (poly)phenols from tomatoes and peppers was higher than that of processed foods prepared with them as main ingredients (Lucas-González et al., 2023).

Regarding the four bioaccessible compounds detected in goat cheese enriched with date palm paste, caffeoylshikimic acid glycoside, caffeoylshikimic acid, caffeic acid, and quercetin glycoside 1 (Fig. 3), the differences compared with date paste were pronounced. In the date paste, those compounds showed bioaccessibility index values equal to or exceeding 100 %. In contrast, in both enriched cheese samples (DPC-4 and DPC-8), the bioaccessibility values ranged from 11.10 % to 48.78 %. Among them, caffeic acid was reported the highest bioaccessibility index. Furthermore, no significant differences were found between the two enriched cheese samples ($p > 0.05$), indicating that the low bioaccessibility of date (poly)phenols within the cheese matrix was independent of their initial concentration. López-Astorga et al. (2025) reported higher percentages of compound release in yogurt fortified with 6 % microencapsulated grape pomace extract than those observed in the present study, with values ranging from 11.3 % to 10 277 %. In their case, the degradation of anthocyanins was responsible for the marked increase in syringic acid (10 277 %). As observed in the present work, they also reported variable release of quercetin derivatives: some were no longer detected after digestion, whereas others—such as quercetin dihydrate and isorhamnetin 3-*O*-glucoside—showed release indices of 76.2 % and 80.4 %, respectively. Other authors have subjected dairy products enriched with (poly)phenol -rich extracts to *vitro* digestion; however, phenolic stability in those studies was assessed using colorimetric methods, which offer less accurate results (Coelho et al.,

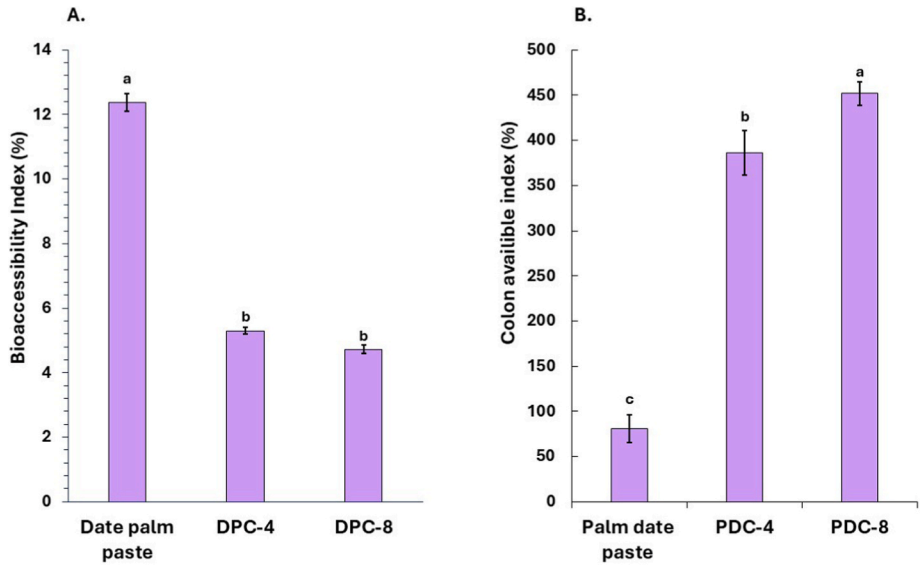

Fig. 1. A) Total bioaccessibility index and B) Colon available index of total (poly)phenols of date palm paste, fresh goat cheese enriched with 4 % of date palm paste (DPC-4) and fresh goat cheese enriched with 8 % of date palm paste (DPC-8).

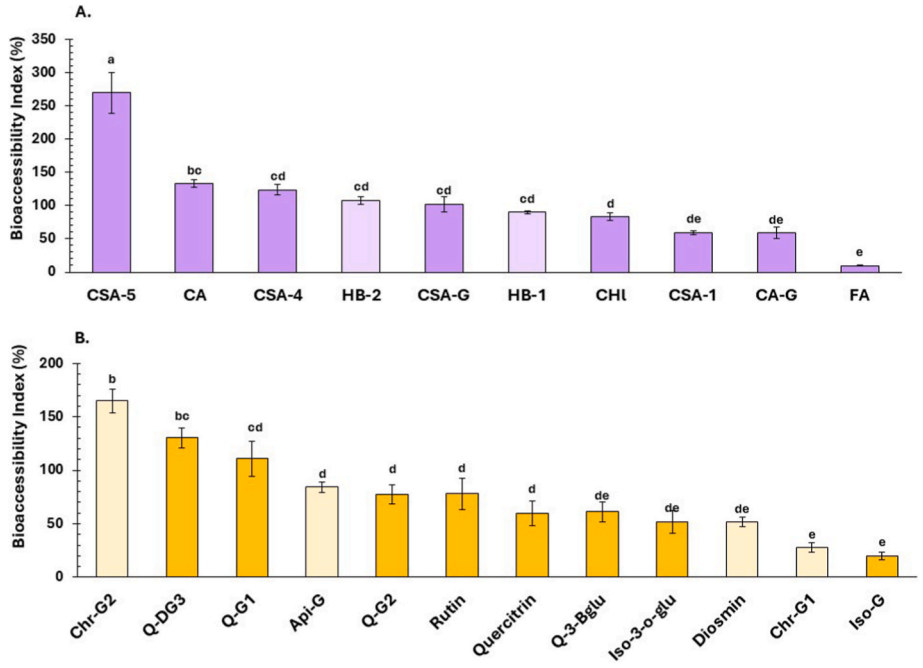

Fig. 2. A) Bioaccessibility index of individual hydroxycinnamic and hydroxybenzoic acids and derivatives of date palm paste. B) Bioaccessibility index of individual Flavonols and flavones from date palm paste.
CSA-5: Caffeoylshikimic acid 5; CA: Caffeic acid; CSA-4: Caffeoylshikimic acid 4; HB-2: Hydroxybenzoic acid derivative 2; CSA-G: Caffeoylshikimic acid glycoside; HB-1: Hydroxybenzoic acid derivative 1; CHl: Chlorogenic acid; CSA-1: Caffeoylshikimic acid 1; CA-G: Caffeic acid glycoside; Fa: Ferulic acid. Chr-G2: Chrysoeriol glycoside 2; Q-DG3: Quercetin diglycoside 3; Q-G1: Quercetin glycoside 1; Api-G: Apigenin glycoside; Q-G2: Quercetin glycoside 2; Q-3-Bglu: Quercetin-3-β-D-glucoside; Iso-3-*O*-glu: Isorhamnetin-3-*O*-glucoside; Chr-G1: Chrysoeriol glycoside 1; Iso-G: Isorhamnetin glycoside.

2024; Zheng et al., 2024).

Concerning the colon available index of the individual insoluble-bound (poly)phenols (Fig. 4), different trends were observed among enriched goat fresh cheese compared with date paste. For vanillin glycosides 1 and 2, similar values were reported among all three samples ($p > 0.05$). In contrast, the colon available index of ferulic acid was lower in date paste than in both enriched goat cheese samples ($p < 0.05$). Conversely, in the case of anthocyanin derivative 3, the highest values were reported for date paste ($p < 0.05$). Therefore, although *in vitro* digestion process favored the increase of these compounds, the results revealed an influence of both the compound structure and the food matrix.

4. Limitations and future recommendations

Studies examining the effect of the food matrix on nutrient digestibility and the bioaccessibility of micronutrients and phytochemicals are still limited. The number of available publications remains low. Moreover, considering the current trend toward developing hybrid foods that combine animal-derived ingredients with plant-based

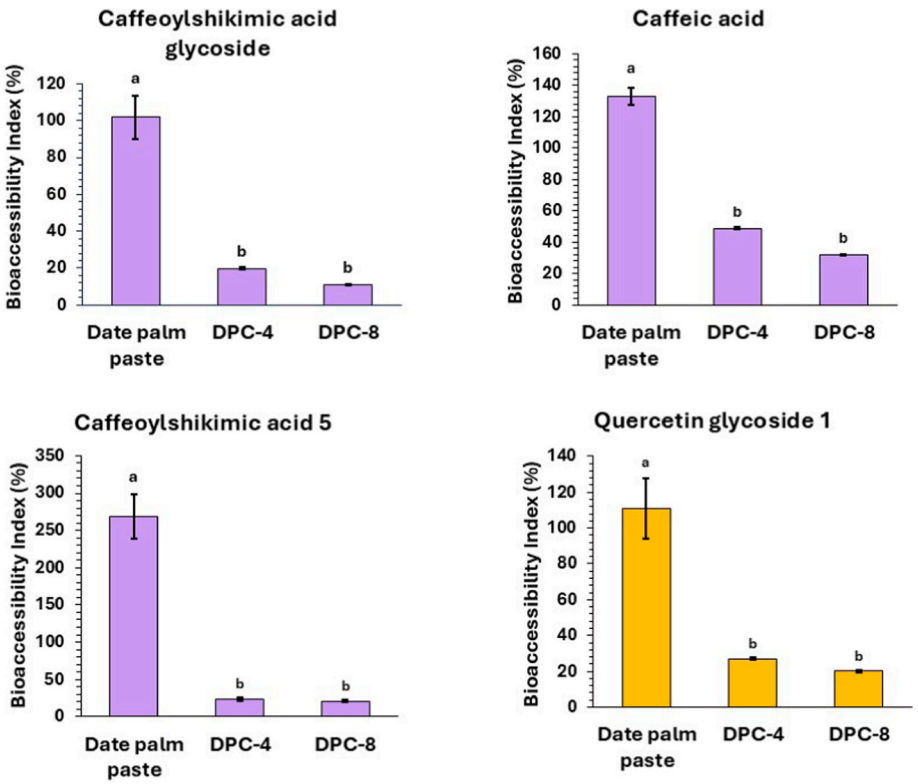

Fig. 3. Bioaccessibility of individual polyphenols of date palm paste, fresh goat cheese enriched with 4 % of date palm paste (DPC-4) and fresh goat cheese enriched with 8 % of date palm paste (DPC-8).

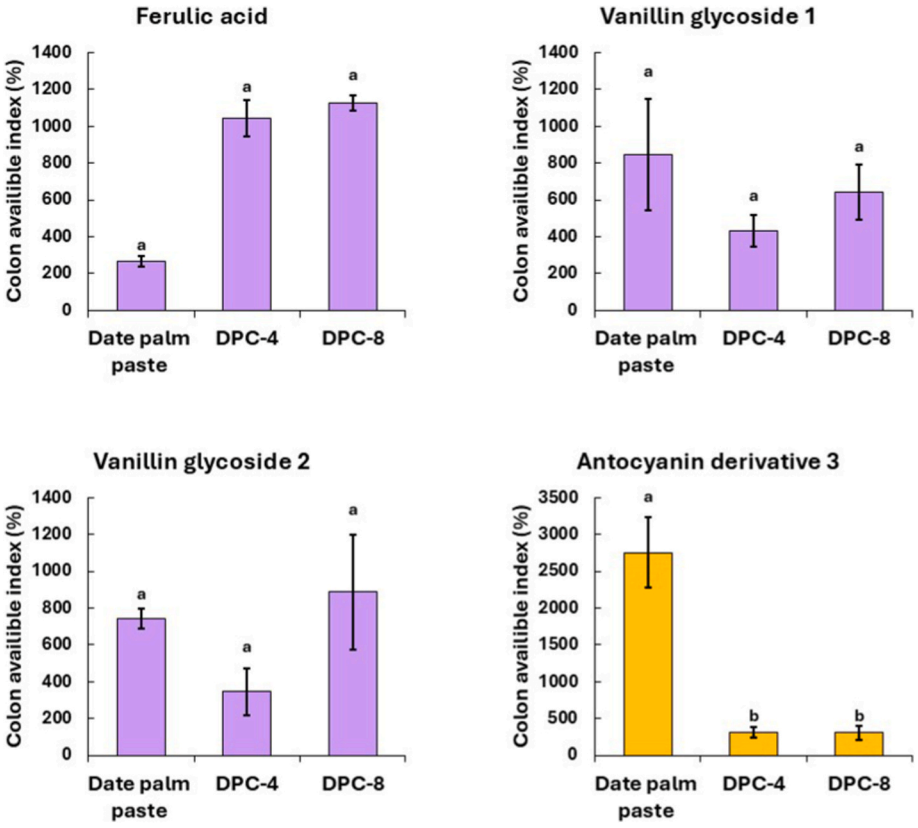

Fig. 4. Individual colon available index of date palm paste, fresh goat cheese enriched with 4 % of date palm paste (DPC-4) and fresh goat cheese enriched with 8 % of date palm paste (DPC-8).

components, it is increasingly necessary to assess their stability during manufactured and behavior during gastrointestinal digestion. The results on the present study indicate that on fresh cheese the study of (poly)phenols concentration on whey is necessary to improve understand the retention behavior and affinity by (poly)phenols with whey milk proteins.

Moreover, although the inclusion of bound (poly)phenols in the bioaccessibility assessment represents a significant advancement, given that these compounds are often overlooked, future research should also address other relevant fractions, such as conjugated (poly)phenol s, as well as the interactions between (poly)phenol s and proteins. Such analyses are necessary to investigate in depth the interactions, stability, and behavior of (poly)phenol s within their intrinsic matrix and in other food matrices, including dairy products. Furthermore, while *in vitro* digestion models provide a valuable tool for preliminary investigation, complementary *in vivo* studies are required to fully elucidate the physiological implications of these interactions in the human body.

5. Conclusions

Date palm paste (*Phoenix dactylifera*, Confitera variety) is a valuable source of (poly)phenols, including a substantial bound-insoluble fraction that is often underestimated in date fruits. *In vitro* gastrointestinal digestion showed that the cheese matrix markedly reduced the stability and bioaccessibility of these compounds, with recoveries below 40 % regardless of enrichment level. The digestion process also introduced substantial changes to the (poly)phenol profile, demonstrating that the composition of the raw material alone does not reflect the compounds ultimately available for absorption or colonic metabolism.

These findings indicate that incorporating date palm paste into dairy products can enhance their content of colon-available (poly)phenols but also highlight the need to improve food formulation strategies to better preserve (poly)phenol stability and release during digestion. Optimizing factors such as processing conditions, microencapsulation, or matrix interactions may increase the effectiveness of (poly)phenol delivery in hybrid dairy–plant foods. Further research is required to clarify the interactions between these compounds and the colonic microbiota and to better understand their potential health implications. In conclusion, the study pointed out that the food matrix plays a decisive role in modulating the release and stability of (poly)phenols during digestion.

CRediT authorship contribution statement

Raquel Lucas-González: Writing – review & editing, Writing – original draft, Validation, Methodology, Data curation, Conceptualization. **Clara Muñoz-Bas:** Writing – original draft, Investigation, Formal analysis. **Nuria Muñoz-Tebar:** Methodology, Formal analysis. **José Ángel Pérez- Álvarez:** Investigation, Funding acquisition. **Manuel Viuda-Martos:** Writing – review & editing, Methodology, Investigation. **Juana Fernández-López:** Writing – review & editing, Writing – original draft, Supervision, Resources, Conceptualization.

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Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2026.119019.

Data availability

Data will be made available on request.

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