Applied Food Research 4 (2024) 100619

Contents lists available at ScienceDirect

Applied Food Research

journal homepage: www.elsevier.com/locate/afres

Application of date-coproducts for the fortification of fresh goat cheese: Effect on their nutritional, technological, physicochemical, microstructural, microbiological and sensory properties

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A R T I C L E I N F O

Key words:
Fresh cheese
Goat milk
Coproducts
Date fruit
Fortification
Dairy products

A B S T R A C T

A sustainable approach for the fortification of fresh goat cheese, while reducing food industry waste, is adding date coproducts (as date paste) to the cheese. The addition of date paste (up to 8 %) during the fresh cheese making did not affect its technological viability with yield production (17.8–23.3 %) and pH values (5.43–5.73) within the range of traditional goat fresh cheeses. Nutritionally, the addition of date paste (DP) resulted in cheeses with better fatty acid profile (higher MUFA content) and higher mineral content (specially K, 44 % higher in cheese with 8 % DP compared to control). In reference to LAB, fortifying cheeses with DP increased their counts (Lactobacillus spp rising from 7.43 to 8.30 $\log_{10}$ CFU/g and Streptococcus spp from 6.11 to 7.45 $\log_{10}$ CFU/g), with the rise being proportional to the amount of DP added. Regarding texture, the fortification of goat cheeses with DP did not affect either their cohesion or resilience which was confirmed by the microstructure analysis showing that the DP was integrated into the protein matrix, preserving the characteristic protein-lipid network of fresh goat cheese. Sensorially, the incorporation of DP did not affect the aroma, flavor, sweetness (although fructose and lactic acid content was higher in fortified cheeses), salty and fracturability of the cheeses.

1. Introduction

According to the UN's latest report, the world population will reach 9.8 billion by 2050 and 11.2 billion by 2100 (United Nations, 2017). This growth inevitably demands an increase in food production (not only raw materials but also processed foods). In this scenario, it will be crucial to explore new food sources (e.g. insects and seaweeds), while reducing food waste by transforming co-products into value-added products. In particular, the co-products generated from the industrialization of fruits and vegetables are rich in essential nutrients and bioactive compounds. These bioactive compounds offer a range of health benefits due to their antioxidant, antimicrobial, and anti-inflammatory properties (Aqilah et al., 2023), which, in turn, are associated with the control of the development and progression of most chronic diseases like obesity, diabetes, cardiovascular diseases, neurodegenerative disorders, and cancer (Kainat et al., 2022).

The industrialization of fresh dates generates a large amount of co-products that can be transformed into high value-added ingredients for enriching various foods when they are subjected to environmentally friendly and sustainable methods (Muñoz-Bas et al., 2023, 2024; Muñoz-Tebar et al., 2023). Date paste is one of these value-added products, whose composition (rich in sugars, dietary fiber, and minerals such as K, Ca and Mg) and techno-functional properties (water holding capacity and swelling capacity) make it a suitable ingredient for the dairy industry (Muñoz-Bas et al., 2024). It has already been successfully used to fortify goat yogurts achieving an improvement in the growth and stability of the yogurt starter culture, thereby enhancing the probiotic potential of date-enriched yogurts (Muñoz-Tebar et al., 2024). Based on these results fresh goat cheese could also serve as an interesting matrix to incorporate date co-products.

Due to the nutritional content and health benefits associated with dairy consumption (Verruck et al., 2019) along with their great consumer acceptance and the wide versatility of the dairy matrix, food industry has been a pioneer in adding these value-added compounds into dairy products. In this sense, different value-added ingredients derived from fruits and their co-products (e.g. citrus, banana, dragon fruit and

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https://doi.org/10.1016/j.afres.2024.100619
Received 20 October 2024; Received in revised form 13 November 2024; Accepted 21 November 2024
Available online 22 November 2024

strawberries among others) are commonly obtained as a paste or even as a powder and are rich in dietary fiber and other bioactive compounds (mainly polyphenols). These value-added ingredients have been incorporated into a range of dairy products with different purposes such as stabilizer or texturizer in yogurts, as antioxidants, and as source of fiber to fulfill dietary needs, increasing satiety and regulating appetite (Dantas et al., 2022; Kowaleski et al., 2020; Wu et al., 2023). Cheese has been also reported as an excellent matrix for the incorporation of these value-added ingredients obtained from fruit co-products, improving their nutritional, functional and technological properties (Basiony et al., 2023; El-Loly et al., 2022; Mehanna et al., 2017). In the case of ice creams, these compounds have been used to reduce the high levels of fat and sugars in their formulation, while improving their physico-chemical and technological properties(de Oliveira et al., 2021; Utpott et al., 2020) as well as their organoleptic properties including sweetness, taste, color and flavor (Curti et al., 2021; Salehi, 2021). In all cases, their application in dairy products has enhanced the profile of bioactive compounds and boosted their antioxidant properties (Boyanova et al., 2022; Haghani et al., 2021).

Consumers perceive goat cheese as healthier than cheese made from cow's milk and is highly appreciated for its nutritional value, easy digestibility and low allergenic properties. Not only does it contain less lactose, making it a better option for people with lactose intolerance, but goat cheese also appeals to health-conscious consumers due to its high levels of calcium and other vitamins and minerals (Sant'Ana et al., 2013). In addition, goat milk has been associated with certain therapeutic values in human nutrition (Caleja et al., 2015; Díaz-Castro et al., 2012; Haenlein, 2004). The goat cheese market size was valued at approximately US$ 5.72 billion in 2022 and is estimated to reach around US$ 8.64 billion by 2030. Due to a variety of driving factors, the market is expected to grow at a significant rate. By region, Europe was the leading revenue generator in 2022, with fresh cheese being the most popular form (Zion, 2024). This type of cheese is traditionally made from pasteurized goat's milk, and it is a soft, pressed cheese with enzymatic coagulation characterized by a mild, acidic flavor, typical of fresh goat's milk as well as slightly salty. The aim of this work was to evaluate the effect of two concentrations (4 % and 8 %) of date paste obtained as an intermediate food ingredient from the valorization of date coproducts (Confitera cv.) on the nutritional, technological, physicochemical, microstructural, microbiological and sensory properties of fresh goat's cheese.

2. Materials and methods

2.1. Materials

The goat milk was collected from the farm of the Miguel Hernandez University (Orihuela, Alicante, Spain). The date paste (from co-products of date fruit, Confitera cv.) was obtained following the procedure described by Muñoz-Bas et al. (2024). Starter culture CHOOZIT MA4001 was purchased from Danisco (Sassenage, France) while rennet and calcium chloride ($CaCl_2$) were obtained from Arroyo Laboratories (Santander, Spain).

2.2. Cheese making

Goat milk (60 L) was pasteurized (72 °C/15 s) and separated into three batches of 20 L each (control, DP4: 4 % DP added, and DP8: 8 % DP added). The milk was cooled to 30 °C and the starter culture was added at 0.05 Danisco culture units (DCU)/L. After that, DP was incorporated to milk followed by the addition of microbial rennet 1:15,000 (20 mL/L), $CaCl_2$ (0.25 mL/L) and salt (7 g/L). Then, vats were allowed to coagulate for 45 min, cut and stirred for 10 min. Finally, cheeses were molded and stored refrigerated at 4–8 °C and relative humidity 85 % until further analysis. Fig. 1 shows the fresh cheeses developed. The yield of cheese was calculated as: [(kilograms of cheese/ kilograms of milk) x 100].

2.3. Proximate composition

Proximate composition was determined in triplicate following AOAC methods (AOAC, 2006). Moisture content was measured by drying 2 g of sample in a vacuum oven (AOAC 925.45). Protein content was estimated from the analysis of the nitrogen content through the Kjeldahl micro method, using a conversion factor of 6.38 for milk and dairy products (AOAC 981.10). The ash content was assessed by the incineration of 2 g of sample at 550 °C until the total elimination of organic matter (AOAC 923.03). The fat content was determined by the Gerber method using a butyrometer where 10 mL of sulfuric acid and 1 mL of amyl alcohol were added to 5 g of sample.

2.4. Fatty acid profile

Fatty acid profile of the cheeses was analyzed by extracting and

Fig. 1. Appearance of fresh goat cheeses fortified with different proportions of date paste.
Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added.

methylating the lipids. The resulting fatty acid methyl esters (FAMEs) were quantified using gas chromatography (GC) under the same conditions described by Pellegrini et al. (2018). Briefly, an autosystem chromatographer (Perkin Elmer – Beaconsfield, UK) equipped with a VF–23 ms fused silica capillary column (30 × 0.25 mm × 0.25 µm film thickness, Varian – Middelburg, The Netherlands) and a flame ionization detector (FID) were used. The column was maintained at 60 °C for 1 min after injection, the temperature was set at 130 °C (10 °C/min), then the temperature was set at 170 °C (3 °C/min) and the last ramp at 230 °C (10 °C/min), hold during 5 min. Helium was used as a carrier gas with a column inlet pressure set at 20 psi and a split ratio of 1:20. The injection volume was 0.5 µL and the total analysis time was 32 min. The injector and detector temperatures were set at 250 °C and 270 °C, respectively. All measurements were performed in triplicate and the results were reported as g FAME/100 g of fat.

2.5. Organic acids and sugar composition

Sugars and organic acids of fresh goat cheese added with date paste were extracted using the method described by Muñoz-Bas et al. (2024). After extraction, 20 µl of each sample were injected into an HPLC (Hewlett-Packard 1100 series, Woldbronn, Germany) equipped with a Supelco Supelcogel™ C-610H column (300 mm x 7.8 mm). Orthophosphoric acid in water (0.1 % v/v) was used as the elution buffer and organic acids were quantified by measuring absorbance at 210 nm with a diode array detector (DAD G-1315 A), while sugars were detected using a refractive index detector (RID G1362A).

2.6. Mineral composition

To analyze the mineral composition of fresh goat cheese enriched with date paste, samples were lyophilized using a Freeze Dryer Alpha 2–4 (Martin Christ Gefriertrocknungsanlagen GmbH, Germany) and digested with nitric acid (67 %) and hydrogen peroxide (33 %) via microwave. Minerals (Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn) were quantified using inductively coupled plasma mass spectrometry (ICP-MS) on a Shimadzu MS-2030 (Shimadzu, Kyoto, Japan) under the same conditions used by Muñoz-Bas et al. (2023). Each cheese formulation was analyzed in triplicate and the results were expressed as mg/100 g cheese.

2.7. Physicochemical properties

The pH of cheeses was measured with a pH-meter Sension + pH31 (HACH, Spain) and water activity using a NOVASINA TH-200 hygrometer (Novasina; Lachen, Switzerland). CIELAB color coordinates were determined using a Minolta CM-700d spectrophotocolorimeter (Konica Minolta, Osaka, Japan) with a D65 illuminant and a 10° observer angle. From these coordinates, the psychophysic attributes (chroma and hue), the whiteness index (WI) and the color differences (ΔE*) respect to control cheese were calculated (Muñoz-Bas et al., 2024). All measurements were performed in triplicate.

2.8. Texture

A Texture Profile Analysis (TPA) was conducted using a TA-XT2i texturometer (Stable Micro Systems Ltd., Godalming, Surrey, UK) equipped with a 5 kg load cell and a cylindrical aluminum P/100 probe. Cheese samples were cut into 1.5 cm cubes compressed twice to 25 % of its original height at a speed of 1.3 mm/s, with a 5-second recovery time between compressions. Ten measurements were made per sample and the results were expressed as hardness (N), adhesiveness (N·seg), springiness, cohesiveness and resilience.

2.9. Confocal laser scanning microscopy (CLSM)

The microstructures of the fresh goat cheese samples were analyzed using a Leica SP5 confocal laser scanning microscopy (TCS-SPE, Leica Microsystems, Heidelberg, Germany) following the method described by Muñoz-Tebar et al. (2022) with slight modifications. Samples were cut into 95-µm-thick serial sections with an HM400 microtome (Microm, Walldorf, Germany) and soaked in fluorescence stains for around 10 min. The staining was performed using a combination of Fast Green FCF and Nile Red. Both stains were obtained from Sigma-Aldrich (Madrid, Spain) and prepared as stock solutions (1 mg/mL in deionized water for Fast green FCF and Lectin FITC and in dimethylsulfoxide (DMSO) for Nile red). These stock solutions were then diluted with deionized water and DMSO to achieve a final concentration of 0.1 mg/mL just before staining. Nile Red was excited at 488 nm, while Fast Green FCF was excited at 633 nm. The emission filters were set to 520–590 nm for Nile Red and FITC lectins, and to 660–750 nm for Fast Green FCF.

2.10. Microbiological quality

Total aerobic count, LAB, Enterobacteria and Molds and Yeasts of fresh goat cheeses incorporated with date paste was evaluated following the procedure described by Muñoz-Tebar et al. (2024). Briefly, samples were manually inoculated in duplicate on MRS agar for *Lactobacillus* spp. and M17 agar for *Streptococcus* spp., followed by incubation at 37 °C for 48 h. *Streptococcus* spp. was incubated under normal conditions, while *Lactobacillus* spp. was incubated in an anaerobic chamber using Anaerocult A (Merck, Darmstadt, Germany). For total aerobic count, enterobacteria, molds, and yeasts, Petrifilm plates (3M, Madrid, Spain) were inoculated and incubated at 37 °C for 24 h (total aerobic), 37 °C for 24 h (enterobacteria) and at 25 °C for 120 h (molds and yeasts). Plates (30–300 colony-forming units (CFU)) were manually counted expressing the results as $\log_{10}$ CFU/g of cheese.

2.11. Sensory analysis

To assess the sensory acceptability of cheese made with date paste, fifty consumers (60 % female, 40 % male, aged 18 to over 65) were recruited from the students and staff of the Orihuela Polytechnical High School at Miguel Hernández University (UMH) who were regular consumers of goat's cheese. Sensory evaluations (consumer study) were conducted in the standardized sensory laboratory at UMH, which complies with international standards (ASTM, 1986). Participants were seated in individual booths under TL 5 fluorescent lighting (Philips-Ibérica, Madrid, Spain) with an intensity of approximately 350 lx. Cheese samples (pieces of 2 × 2 cm obtained from the inner part of the cheese), each labeled with a random 3-digit code, were served in a blind, fully randomized order in transparent plastic cups. Consumers were asked to evaluate the following 9 attributes (selected based on the most appreciated by cheese consumers or those most likely to be modified by the incorporation of date paste): odor, taste, color, sweetness, salty, firmness, fracturability, granularity, and overall acceptability. A discrete 9-point hedonic scale ranging from "dislike extremely" (1) to "like extremely" (9) was used (Ramirez-Rivera et al., 2018).

2.12. Statistical analysis

Data analysis was conducted using SPSS (IBM SPSS Statistics version 26). A one-way ANOVA was applied with a 95 % confidence level to identify any significant differences between the control cheese and those added with date paste (4 % and 8 %). When significant differences were found ($p < 0.05$), Tukey's test was performed to identify specific differences between the cheese formulations. All the analysis were performed using 5 independent samples ($n = 5$) and all the assays were carried out in triplicate, except for texture analysis (10 repetitions).

3. Results and discussions

3.1. Cheese yield

Cheese yield (kg cheese/100 L milk) is a crucial parameter to evaluate the viability and efficiency of the cheese-making process and it is partially determined by the overall quality of the milk used for its production (Guo et al., 2004). The addition of DP decreased the cheese yield in a concentration-dependent manner, but all the values obtained (Control: 23.37 %; DP4: 19.83 %; DP8: 17.78 %) were within the normal range for artisanal fresh goat's cheese (Vacca et al., 2018). Cheese yield is affected by many factors including milk quality (milk composition, pasteurization, etc.) and cheese-making conditions (coagulant type, vat design, curd firmness at cutting and others manufacturing parameters) (Cipolat-Gotet et al., 2013). Given that the only difference among the 3 formulation was the DP addition, it is likely that the effect of DP has on the cheese curd formation and on its physicochemical and rheological properties was a key factor in these values.

3.2. Proximate composition

The nutritional values of cheeses depend on milk characteristics and conditions occurring during their technological processing. In addition, the chemical composition of goat milk is influenced by several factors, including the breed, individual differences among goats, diet, season, stage of lactation, and environmental conditions (Guo et al., 2004). Proximate composition of goat cheeses formulated with DP is presented in Table 1, noticing that the composition of the DP added also contribute to their nutritional value. Cheeses with DP added displayed a higher moisture content and a lower protein content ($p < 0.05$) compared with control cheese while there were not differences ($p > 0.05$) for these two parameters among the two DP added cheeses (DP4 and DP8). Date paste is likely responsible for increasing moisture retention during cheese manufacturing, mainly due to its water holding capacity (Muñoz-Bas et al., 2024). On the contrary, fat and ash content were not affected ($p > 0.05$) by DP addition. Like goat milk, fat was the main component in fresh cheeses after the moisture content. For all cheeses, the levels of moisture, fat, protein and ash were within the normal range for fresh goat milk cheeses (Kawęcka & Pasternak, 2022; Masotti et al., 2012).

3.3. Lipid profile

The fatty acid profile of the control and fortified fresh goat cheeses is shown in Table 2. The addition of DP did not affect the lipid profile of cheeses, except for oleic acid (C18:1), which increased and capric acid (C10:0) that decreased ($p < 0.05$) in DP-added cheeses. This behavior could be due to the fact that oleic acid (C18:1) is the major fatty acid in date fruits (Ogungbenle, 2011) and capric acid (C10:0) one of the most characteristic fatty acids in goat milk (Vieitez et al., 2016). Capric acid (C10:0) was the predominant short chain fatty acids (SCFA) in all cheeses, with a value exceeding 7 % of the total fatty acids in control cheese, consistent with the results reported by other authors (Paszczyk & Łuczyńska, 2020). The major fatty acids in all cheeses were palmitic acid (C16:0) followed by oleic acid (C18:1), representing the sum of more than 50 % of the total fatty acids (56.1–58.5 %). It has been reported that proportions of specific groups of fatty acids in foods are considered particularly important from a nutritional point of view (Paszczyk & Łuczyńska, 2020). Saturated fatty acid (SFA) was the main fraction (ranging from 63.4 to 64.0 %) followed by monounsaturated fatty acids (MUFA; ranging from 27.2 to 27.7 %) and a small proportion of polyunsaturated fatty acids (PUFA; ranging from 5.1 to 5.3 %). It is important to highlight that while the specific content of individual PUFAs (C18:2 and C18:3) did not differ significantly ($p > 0.05$) between the cheeses, the overall PUFA fraction was ($p < 0.05$), with the DP-added cheeses (DP4 and DP8) showing slightly higher PUFA content than the control (Table 2). Traditionally, the high levels of SFA in dairy products have been linked to negative health effects and an increased risk of conditions such as obesity, diabetes and cardiovascular diseases, among others. However, recent findings suggest that this relationship may be less straightforward than previously assumed. Other nutrients and various associated factors appear to significantly influence the lipoprotein metabolism, which plays a key role in the development of these diseases (Gómez-Cortés et al., 2018; Paszczyk & Łuczyńska, 2020). On the other hand, cheeses also contain other lipid fractions that are related to positive health aspects. For instance, SCFAs are important in promoting human health (Gómez-Cortés et al., 2018; Hanuš et al., 2018), while MUFAs (oleic acid) exhibit anti-cancer and anti-atherogenic properties, making them beneficial for daily consumption (Hanuš et al., 2018), and PUFAs provides protection against several diseases (Kapoor et al., 2021).

Table 1
Proximate composition (mg/100 g cheese) of goat cheeses formulated with date paste (DP).

Sample	% Protein	% Fat	% Ash	% Moisture
Control	13.52 ± 0.16[a]	22.87 ± 1.50[a]	2.33 ± 0.06[a]	60.23 ± 0.66[B]
DP4	12.42 ± 0.25[B]	22.29 ± 0.57[a]	2.19 ± 0.10[a]	63.07 ± 0.43[a]
DP8	12.65 ± 0.42[B]	22.23 ± 0.72[a]	2.13 ± 0.15[a]	62.94 ± 0.60[a]
p-value	0.009	0.715	0.155	0.001

[a-b] Different letter in the same column indicate significant differences based on Tukey' test ($p < 0.05$).

Data ($n = 5$; Mean ±standard deviation). Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added.

Table 2
Fatty acid profile of goat cheeses formulated with date paste (DP).

Sample	Control	DP4	DP8	p-value
Caprylic acid (C8:0)	1.72 ± 0.18[a]	1.43 ± 0.08[a]	1.43 ± 0.14[a]	0.200
Capric acid (C10:0)	7.65 ± 0.35[a]	6.78 ± 0.15[b]	6.83 ± 0.48[b]	0.046
Lauric acid (C12:0)	4.10 ± 0.03[a]	3.88 ± 0.01[a]	3.88 ± 0.14[a]	0.119
Myristic acid (C14:0)	9.60 ± 0.09[a]	9.53 ± 0.03[a]	9.51 ± 0.10[a]	0.51
Palmitic acid (C16:0)	31.09 ± 0.28[a]	31.73 ± 0.09[a]	31.63 ± 0.30[a]	0.141
Palmitoleic acid (C16:1)	1.19 ± 0.36[a]	0.96 ± 0.01[a]	0.95 ± 0.01[a]	0.506
Stearic acid (C18:0)	9.85 ± 0.06[a]	10.11 ± 0.06[a]	10.11 ± 0.17[a]	0.161
Oleic acid (C18:1)	25.97 ± 0.05[b]	26.73 ± 0.02[a]	26.63 ± 0.31[a]	0.046
Linoleic acid (C18:2, Ω−6)	3.87 ± 0.03[a]	4.02 ± 0.00[a]	4.01 ± 0.04[a]	0.056
α-linolenic acid (C18:3, Ω−3)	1.20 ± 0.02[a]	1.26 ± 0.01[a]	1.29 ± 0.01[a]	0.630
∑ SFA	64.03 ± 0.25[a]	63.46 ± 0.05[a]	63.40 ± 0.39[a]	0.171
∑ MUFA	27.16 ± 0.30[a]	27.69 ± 0.03[a]	27.58 ± 0.33[a]	0.238
∑ PUFA	5.07 ± 0.06[b]	5.28 ± 0.01[a]	5.30 ± 0.05[a]	0.035

[a-b] Different letters in the same row indicate significant differences based on Tukey' test ($p < 0.05$).

Data ($n = 5$; Mean ±standard deviation). SFA: saturated fatty acids; MUFA: unsaturated fatty acids; PUFA: polyunsaturated fatty acids. Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added.

3.4. Sugar and organic acid composition

Table 3 shows the sugar and organic acids concentration of the fresh goat cheese enriched with date paste. The main sugar found in all the

Table 3
Sugars (lactose and fructose) and organic acids (lactic and citric acids) content (mg/g) of fresh goat cheeses with date paste (DP).

Sample	Lactose	Fructose	Citric acid	Lactic acid
Control	27.35 ± 0.14[a]	ND[c]	3.64 ± 0.07[a]	8.64 ± 0.19[b]
DP4	27.33 ± 0.24[a]	1.81 ± 0.02[b]	3.56 ± 0.10[a,b]	12.87 ± 0.02[a]
DP8	27.97 ± 0.13[a]	3.66 ± 0.04[a]	3.31 ± 0.01[b]	14.50 ± 1.36[a]
p-value	0.062	0.000	0.030	0.011

[a-c] Different letters in the same column indicate significant differences based on Tukey' test ($p < 0.05$).

ND: not detected; Data ($n = 5$; Mean ±standard deviation). Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added.

cheeses was lactose, with concentrations ranging from 27.3 to 28.0 mg/g, showing no significant differences ($p > 0.05$) between the control cheese and those formulated with DP. Fructose was only detected in DP-added cheeses, suggesting that its presence is due to the incorporation of this date coproduct, which contains 137.72 mg/g of fructose (Muñoz-Bas et al., 2024). Furthermore, the fructose content increased proportionally with the amount of date paste added to the cheeses (DP4: 1.8 mg/g vs. DP8: 3.7 mg/g). As expected, lactic acid was the major organic acid followed by citric acid (Table 3). The content of lactic acid increase with the incorporation of DP varying from 8.6 to 14.5 mg/g, with the highest value found in DP8 cheese. This increase in lactic acid content caused by the incorporation of DP is related to the behavior observed in LAB counts (point 3.9), which were higher in DP-added cheeses. On the other hand, citric acid content slightly decreased with the addition of date paste (from 3.6 to 3.3 mg/g), being proportional to the increase in date concentration in the cheeses. Moreira et al. (2020) reported a similar profile of organic acids (lactic and citric acid as the major) and sugars (mainly lactose) in goat cheese at the beginning of the ripening period (Day 1), being comparable to a fresh cheese. Therefore, it could be said that the values and profile of sugars and organic acids for all the cheeses fall within the range reported in the literature for goat cheese.

3.5. Mineral composition

The fortification of goat cheeses with DP significantly increased ($p < 0.05$) the content of all analyzed minerals (Ca, Cu, Fe, K, Mg, Mn, Na and Zn) compared to the control (Table 4). The major minerals found in all goat cheeses were Na, Ca, K and Mg and the high Na content is mainly due to the salt addition during cheese making. Among all these macro-elements, K showed the greatest increased the most (44 % in cheese with 8 % DP compared to control) likely due to the incorporation of date paste since this co-product, obtained from dates at Tamar stage of the Confitera cv., is an excellent source of K (658 mg/100 g; Muñoz-Bas et al. (2024)). In addition, this date paste is also rich in Mg, Ca and Na (Muñoz-Bas et al., 2024) which could also contribute to the increases of these minerals in DP-fortified cheeses. Calcium is another essential microelement in cheese making (and it is often added during the process) because it binds strongly to casein in milk. However, a significant proportion of calcium is solubilized by the lactic acid produced during fermentation and is removed during the draining (Guo et al., 2004). Once the cheese production is complete, both Ca and Mg have been reported as the main macroelements linked to the solid phase of the cheese, which suggests low mobility and minimal loss during storage (Herman-Lara et al., 2019). Regarding the microelements, the significant increase in Zn, Mn and Cu in the cheeses due to DP incorporation is related to the content of these minerals in the date paste (Muñoz-Bas et al., 2024). The highest increase was observed in the Cu (from 0.01 to 0.06 mg/100 g cheese) and Mn (0.07 vs. 0.12 mg/100 g cheese) contents while Zn showed the lower increase (from 1.43 to 1.98 mg/ 100 g cheese). Several factors that can influence the mineral content of goat cheeses, leading to wide variability in reported data. However, our results are within the ranges reported by other authors (Herman-Lara et al., 2019; Moreno-Rojas et al., 2010). Based on the recommended dietary allowance (RDA) or, where the RDA is unavailable, the adequate intake (AI) for minerals in an adult male (30–50 years) as defined by the EFSA (EFSA, 2024), it has been estimated that consuming 100 g of DP8 cheese would provide the following daily mineral values: 54 % of the AI of Ca, 38 % of the RDA of P, 36 % of the AI of Na, 18 % of the RDA of Zn, 16 % of the AI of Fe, 5 % of the RDA of Mg, 5 % of the AI of Mn and 3 % of the AI of K.

3.6. Pysicochemical properties

Physicochemical parameters of control and DP-fortified cheeses are showed in Table 5. It can be observed that all the cheeses showed pH values within the usual range for fresh cheeses (5.3–6.0). In general, cheese is more acidic (lower pH) than milk (6.5–6.7 in goat milk), and this increased acidity has a positive impact on several characteristics in cheese, such as food safety, texture and flavor. The addition of DP caused a slight pH decrease ($p < 0.05$) of cheese compared to the control (from 5.73 to 5.57 in cheese with 8 % DP). This decrease in pH has also been reported by other authors in cheese incorporated with fruit extracts rich in phenolic compounds (Ferreira et al., 2024; Jeong et al., 2017; Soliman et al., 2022). Water activity (Aw) is an important biophysical factor in cheese making, as it involves a transformation of milk, a perishable liquid, into a semi-solid product with a limited shelf-life, depending on the type of cheese. In fresh cheeses, the added salt and the draining process have the greatest influence on their Aw. In this case, there were no significant differences ($p > 0.05$) in water activity between control and DP-added cheeses (Table 5), with all Aw values within the normal range for fresh cheeses (0.941–0.961; Trmčić et al. (2017)).It is important to note that although DP-added cheeses showed higher moisture content than control (Table 1), their water activity values were similar,

Table 4
Mineral profile (mg/100 g) of goat cheeses formulated with date paste (DP).

Sample	Control	DP4	DP8	p-value
Ca	503.97 ± 2.94[c]	517.82 ± 6.43[b]	536.86 ± 4.51[a]	0.000
Cu	0.01 ± 0.00[c]	0.03 ± 0.01[b]	0.06 ± 0.01[a]	0.000
Fe	0.41 ± 0.01[b]	0.55 ± 0.04[a]	0.63 ± 0.05[a]	0.001
K	98.81 ± 5.06[b]	105.87 ± 1.51[b]	141.00 ± 3.90[a]	0.000
Mg	17.68 ± 0.11[b]	17.71 ± 0.07[b]	22.37 ± 0.56[a]	0.000
Mn	0.07 ± 0.00[b]	0.09 ± 0.01[b]	0.12 ± 0.00[a]	0.000
Na	636.49 ± 14.25[b]	669.96 ± 17.84[b]	778.76 ± 6.63[a]	0.000
P	260.25 ± 3.80[a]	257.22 ± 1.00 [a]	263.49 ± 5.33[a]	0.214
Zn	1.43 ± 0.04[b]	1.46 ± 0.04[b]	1.98 ± 0.14[a]	0.000

[a–c] Different letters in the same row indicate significant differences based on Tukey' test ($p < 0.05$). Data ($n = 5$; Mean ±standard deviation). Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added.

Table 5
Physicochemical properties of goat cheeses formulated with date paste (DP).

Sample	Control	DP4	DP8	p-value
Aw	0.962 ± 0.000[a]	0.961 ± 0.006[a]	0.963 ± 0.002[a]	0.880
pH	5.73 ± 0.04[a]	5.43 ± 0.02[c]	5.57 ± 0.03[b]	0.000
L*(D65)	82.72 ± 0.72[a]	79.90 ± 3.06[a,b]	78.02 ± 3.73[b]	0.035
a*(D65)	−1.50 ± 0.05[b]	−0.57 ± 00.70[a,b]	0.02 ± 1.00[a]	0.007
b*(D65)	6.63 ± 0.18[a]	7.64 ± 1.31[a]	8.82 ± 3.16[a]	0.194
C*(D65)	6.80 ± 0.18[a]	7.69 ± 1.29[a]	8.85 ± 3.20[a]	0.236
h(D65)	102.78 ± 0.58[a]	94.91 ± 5.05[a,b]	90.90 ± 4.99[b]	0.001
WI	81.42 ± 0.70[a]	80.31 ± 0.55[a]	76.74 ± 1.54[b]	0.001
ΔE*		1.33 ± 0.52[b]	5.29 ± 1.35[a]	0.001

[a-c] Different letters in the same row indicate significant differences based on Tukey' test ($p < 0.05$). Data ($n = 5$; Mean ±standard deviation); WI: whiteness index. Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added.

suggesting that water in the DP-added cheeses would be likely bound to the main components of the date paste (sugars and dietary fiber; Muñoz-Bas et al. (2024)) and therefore not available to be involved in the cheese spoilage reactions.

The assessment of color changes in dairy products due to the addition of new ingredients is an important factor in the evaluation of their quality since it is closely associated with overall dairy food quality and eligibility (Lipșa et al., 2024; Nontasan et al., 2012). When it comes to cheese, color is an important trait, although studies have shown that a pleasant mouthfeel and flavor are more important than appearance with respect to overall taste (Milovanovic et al., 2020; Ritvanen et al., 2005). The results of the color properties of the fortified cheese samples are shown in Table 2 showing that yellowness (b*; + yellow/- blue) and chroma (C*; saturation) were not affected ($p > 0.05$) by DP addition. The addition of DP significantly reduced ($p < 0.05$) lightness (L*) and hue (h*; hue angle) values in cheeses, with greater decrease observed as the percentage of DP added increased. Goat cheese has been described as brighter compared with sheep or cow cheese which aligns with the findings reported in the literature (Milovanovic et al., 2020). A decrease in L* values in cheeses has also been reported by several authors due to the addition of vegetable extracts (Caleja et al., 2015; Giroux et al., 2013). Control cheeses showed a lemon-yellow hue, which shifted to a yellow-lemony hues when DP was added (IRANOR, 1981). On the other hand, DP-added cheeses exhibited higher redness values (a*; + red/-green) than control. This decrease in L* and h* values and the increase in a* values in DP-added cheeses compared with control could be attributed to the color properties of DP (L*=30.29; a*=2.51; h*=62.87; Muñoz-Bas et al., 2024). In dairy products, whiteness is often the most critical color characteristic, specifically for fresh cheeses, which generally maintain the milk's original whiteness. Fresh goat's cheeses, in particular, have the highest whiteness mainly because goat's milk has smaller fat globules and undergoes a total conversion of β-carotene (orange-yellow) into vitamin A (colorless) (Milovanovic et al., 2020). The addition of DP decreased the whiteness index in the cheeses, although it was significant only when 8 % DP was added ($p < 0.05$). The relevance of these color changes in the cheeses is also reflected in the color differences (ΔE*) between DP-added cheeses and the control cheeses. DP4 cheese had color differences lower than 3 units which is generally consider imperceptible to the human eye (Martínez et al., 2001). In contrast, DP8 cheese showed color differences higher than 5 units, indicating that its color would be noticeable different from the color of control cheeses. As expected, the incorporation of DP caused significant modifications in the color properties of the cheeses. It should be noted that the DP-fortified cheese exhibited a lemon-yellow hue, but this color was not uniform, instead particles of DP were visible, distributed unevenly both on the surface and throughout the inside of the cheeses (Fig. 1).

3.7. Texture

The texture parameters of control and fortified cheeses with DP, such as firmness, adhesiveness, springiness, cohesiveness, chewiness, and resilience are presented in Table 6. All textural parameters were affected by DP addition except cohesiveness and resilience. Cohesiveness values close to 1.0 indicate that the cheese can withstand the first compression cycle without disintegrating, while values close to 0 suggest complete disintegration (Paredes et al., 2022). In this study, all cheeses showed high cohesiveness values (> 0.85). Resilience, on the other hand, measures how well the cheese can recover its shape after the first compression cycle. Thus, it could be said that the fortification of goat cheeses with DP did not affect either their cohesion or resilience. However, firmness, adhesiveness and springiness were significantly affected ($p < 0.05$) by the concentration of DP added but without a clear tendency. Firmness showed the most noticeable effect varying from DP concentrations: it decreased with the addition of low DP concentrations (4 %) but increased with higher concentrations (8 %), which could indicate that the addition of DP affected the cheesemaking process. The pH changes in the DP-added cheese (Table 5) and its interaction with the enzymes (rennet) and starter cultures are crucial for moisture retention and curd formation (breaking down milk proteins). These factors influence the firmness, elasticity and structure of the curd, ultimately affecting the final texture of the cheese (Milovanovic et al., 2020). Springiness, which is related to the recovery of the material and its viscoelastic properties (Johnson, 2023), was only modified when DP was added at 4 % (decreased), showing control and DP8 cheeses similar values ($p > 0.05$). On the contrary, adhesiveness was only modified when DP was added at 8 % (−0.13 vs −0.04 N*seg). This parameter measures the effort necessary to overcome the attractive forces between the chesses' surface and the surfaces it comes into contact with, such as the tongue, teeth or palate. When DP was added at high concentrations (8 %), it may not have been fully integrated into the lactic matrix and as a result, the high adhesiveness of DP (due to its high sugar content, Muñoz-Bas et al. (2024) would prevail, significantly increasing the chesses' adhesiveness.

3.8. Confocal laser scanning microscopy (CLSM)

Confocal laser scanning microscopy (CLSM) is commonly employed to study food protein gel systems, providing detailed microstructural information about multi-component gel foods. This technique could enhance the analysis of texture and functional properties in cheese formulated with non-dairy ingredients. The CLSM images (Fig. 2) reveal the microstructures of fresh goat milk cheese influenced by the addition of date paste. As shown in Fig. 2, fat globules (red) and minimal pore spaces (black) are dispersed throughout the protein matrices (green) in all cheeses, regardless of the presence of date paste. This study demonstrated a more compact network with fewer pores compared to the observations by Wang et al. (2023) for the same type of cheese. In the control samples, fat globules were randomly dispersed within the casein matrix, displaying a regular spherical shape without any polysaccharides present. However, large fibers from the date paste, significantly larger than the fat globules (50 µm vs. 3–4 µm), were observed. As shown in Fig. 2, the structure of the protein network did not differ with respect to the control cheese and the inclusion of the date paste did not appear to alter the microstructure of the cheese. The date paste was integrated into the protein matrix, preserving the characteristic protein-lipid network of fresh goat cheese. The enlarged details of the CLSM images of cheeses with date paste reveal fat and protein globules embedded within the date fibers, confirming their successful incorporation into the fresh goat cheese.

Table 6
Texture properties of goat cheeses formulated with date paste (DP).

Sample	Firmness (N)	Adhesiveness (N*s)	Springiness	Cohesiveness	Resilience
Control	2.23 ± 0.40[c]	−1.13 ± 0.00[a]	0.18 ± 0.05[a,b]	0.91 ± 0.05[a]	0.50 ± 0.02[a]
DP4	2.74 ± 0.13[b]	−0.70 ± 0.01[a]	0.12 ± 0.03[c]	0.85 ± 0.08[a]	0.45 ± 0.10[a]
DP8	3.16 ± 0.23[a]	−0.04 ± 0.01[b]	0.22 ± 0.03[a]	0.85 ± 0.06[a]	0.41 ± 0.03[a]
p-value	0.000	0.01	0.046	0.468	0.263

[a-c] Different letters in the same column indicate significant differences based on Tukey' test ($p < 0.05$). Data ($n = 5$; Mean ±standard deviation). Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added.

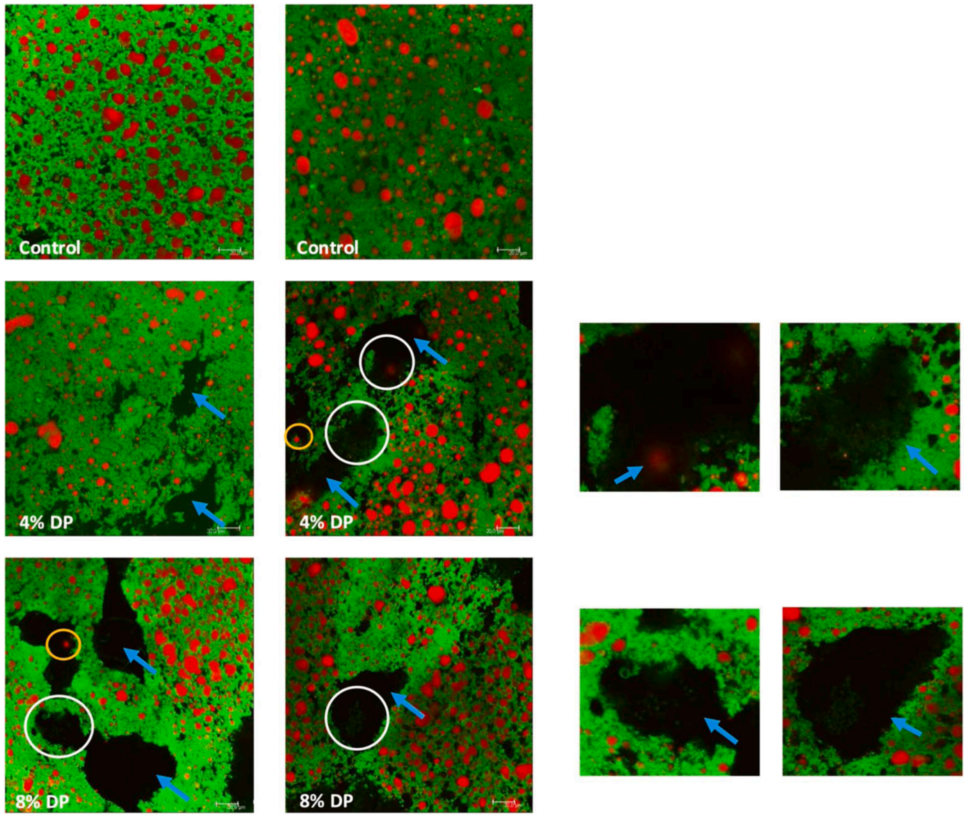

Fig. 2. Effect of incorporation of date paste on the microstructural of fresh goat cheese.
Blue arrows point to the date fibers, fat globules and proteins within the fibers. The Fast green FCF-stained protein appears green and the Nile red-stained lipid bodies appear red. Scale bars= 20 µm.

3.9. Microbiological quality

The incorporation of date paste in the cheese did not impair the development and growth of the starter strains. In fact, as the concentration of date paste increased, LAB counts were higher ($p < 0.05$) compared to control cheese, with *Lactobacillus* spp rising from 7.43 to 8.30 $\log_{10}$ CFU/g and *Streptococcus* spp increasing from 6.11 to 7.45 $\log_{10}$ CFU/g in a way dependent on the content of DP added. However, a significant reduction ($p < 0.05$) in total aerobic counts was observed in DP-fortified cheeses: from 8.05 $\log_{10}$ CFU/g in control cheeses to

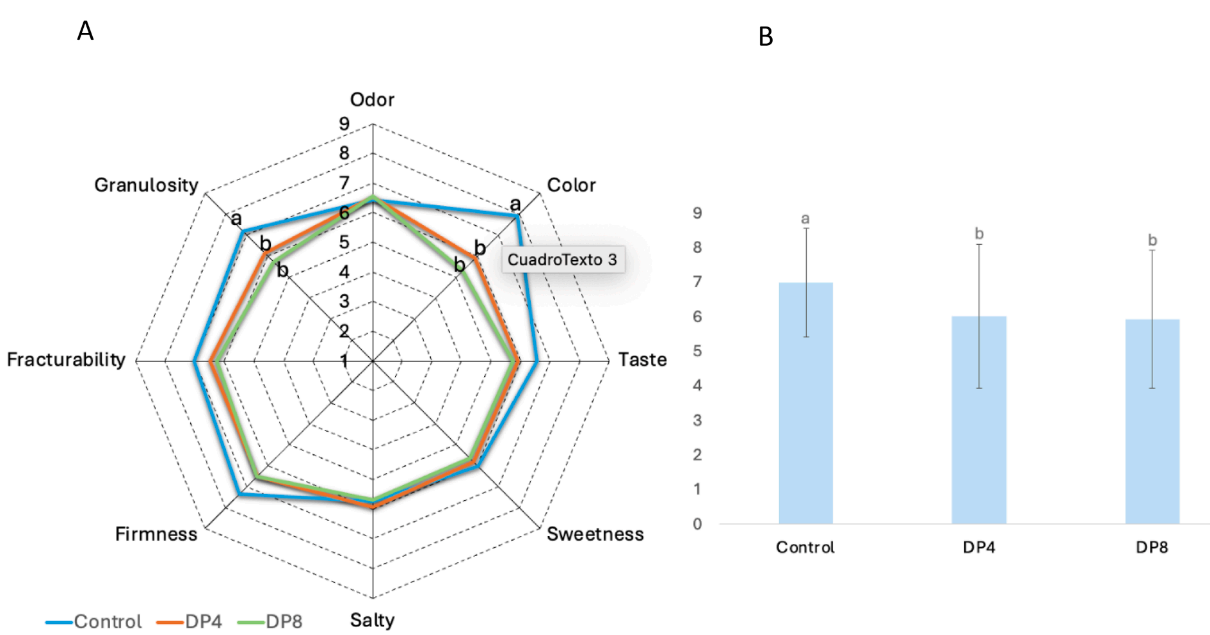

Fig. 3. Sensory evaluation (A) and overall acceptance (B) of fortified goat cheeses.
Control: cheese without date paste added; DP4: cheese with 4 % date paste added; DP8: cheese with 8 % date paste added
Data are presented as mean ± SD. Different letters indicate statistically significant differences as determined by Tukey's HSD post-hoc test ($p < 0.05$).

6.87–6.99 $\log_{10}$ CFU/g in DP-added cheeses. *Enterobacteriaceae* were not detected in any sample, and molds and yeasts were only found at low levels in DP-fortified cheeses (< 2.80 $\log_{10}$ CFU/g). These counts would indicate good sanitary practices during cheesemaking (D'amico, 2014). The presence of molds and yeasts in cheese formulated with date paste is mainly due to date paste itself, as fresh dates can harbor these microorganisms. Nevertheless, they generally develop at a slower rate than bacteria and rarely cause spoilage in such products. Despite the low levels of mold and yeast counts, it would be recommended to pasteurize the date paste, either separately or along with the milk, for future industrial-scale production. Previous studies have reported increases in LAB counts, as well as the presence of molds and yeasts in milk and dairy products enriched with fruit pulp and juices (Basiony et al., 2023; Muñoz-Tebar et al., 2024; Mwangi et al., 2023).

3.10. Sensory properties

Out of the 8 sensory attributes evaluated by the panelists (Fig. 3), significant differences ($p < 0.05$) were only detected between the control and DP-added cheeses in terms of color, firmness, and granularity while the panelists did not detect differences ($p > 0.05$) among DP-fortified cheese. Color, firmness and granularity were scored lower in DP-added cheeses than in control, although in all cases this score was above 5 points. The differences in color and firmness noted by panelists are consistent with the instrumental results (Tables 5 and 6, respectively). The presence of DP particles in fortified cheeses was not positively evaluated by the panelist, which lowered their scores. Additionally, the incorporation of DP did not significantly ($p > 0.05$) affect the aroma, flavor, sweetness (although fructose and lactic acid content was higher in fortified cheeses), salty and fracturability of the evaluated cheeses. It is important to note that the presence of DP (at both concentrations, 4 and 8 %) in the cheeses did not negatively affect the perception of sweetness, obtaining similar values to those obtained for the control cheeses. The sensory results for fracturability align with the results for cohesiveness in the instrumental texture assessment (Table 5). Control cheeses were scored higher ($p < 0.05$) than DP-cheeses for overall acceptability, without significant differences between both concentrations of DP added. However, all scores remained above 5 points, which indicates that the evaluators generally approved all the fresh goat cheeses.

Bearing in mind that the incorporation of dates or their derivatives is not a common practice in the dairy industry, the development of studies that demonstrate the technological feasibility of their application in this matrix would allow the supply of enriched dairy products to be expanded, boosting this sector and increasing the supply of dairy products for the consumer. Furthermore, the fact that the co-products of date industrialisation can be used as a new food ingredient (date paste) that is stable and available all year round, could provide great added value to date production, boosting local development and creating jobs. From the point of view of scientific-technological feasibility, it has been proven that the incorporation of date paste at concentrations of up to 8 % does not interfere in the production process of fresh goat's cheese, i.e. it would not require the incorporation of additional processes or machinery to the traditional ones. However, further research would be needed to scale it up to an industrial level, optimising both the processing conditions and the concentrations of date paste required.

4. Conclusions

The use of date coproducts (such as date paste) for the fortification of fresh goat cheese is a promising sustainable approach, that is both technologically feasible and effective to valorize date production and industrialization. This approach contributes to the reduction of agro-industry waste while, increasing the valued of the resulting cheeses, aligning with sustainable food production practices and the circular economy principles. Date paste properly enhances cheeses by improving their fatty acid profile, increasing beneficial bacteria counts and incorporating micronutrients into the casein matrix, all while preserving the cheese's technological qualities without minimal impact on its sensory attributes.

Funding

This work was supported by the Research Project PID2021–123628OB-C43 funded by MCIN/AEI/10.13039/501,100,011,033 and by "ERDF A way of making Europe. The author Muñoz-Tebar N. is funded by the Margarita Salas Requalification Category Margarita Salas contract of the Universidad Castilla-La Mancha (UCLM, Spain). Part of the analytical equipment used in this study was purchased through the grant EQC2018–004,170-P funded by MCIN/AEI/10.13039/501,100,011,033 and by ERDF "A way of making Europe".

Ethical statement

Protocols for sensory analysis were approved (ref. PRL.DTA.JPA.05.21) by the Project Evaluation Office of the Miguel Hernández University (OEP, UMH, Elche, Alicante, Spain). Participants gave informed consent via the statement "I agree to participate in this survey" where an affirmative reply was required to enter the survey. They were able to withdraw from the survey at any time without giving a reason. The products tested were safe for sensory evaluation.

CRediT authorship contribution statement

Clara Muñoz-Bas: Writing – original draft, Methodology, Investigation, Formal analysis. **Nuria Muñoz-Tebar:** Writing – original draft, Methodology, Formal analysis, Data curation. **Manuel Viuda-Martos:** Visualization, Methodology, Conceptualization. **Estrella Sayas-Barberá:** Resources, Investigation, Funding acquisition. **José Angel Pérez-Alvarez:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Juana Fernández-López:** Writing – review & editing, Visualization, Validation, Supervision, Conceptualization.

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.

Acknowledgments

The authors would like to thank the technical support of the Cátedra Palmeral d'Elx-UMH with the handling of the dates and Dr. Martínez-Navarrete (from UMH) for her assistance with microstructural analysis.

Data availability

Data will be made available on request.

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