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Evaluation of Physico-chemical Properties of Yogurt Low Fat Enriched with *Malus sylvestris* Peel Extract for Antioxidant

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ABSTRACT

Background: The rising demand for functional foods has encouraged the utilization of natural antioxidants from agricultural by-products to enhance food quality and sustainability. Apple peels (*Malus sylvestris*), rich in phenolic compounds like quercetin, offer strong antioxidant properties and health benefits, yet are often discarded as waste. Fortifying yogurt with such bioactive-rich extracts presents an opportunity to improve its functional value while addressing environmental concerns. However, this process requires careful evaluation of how the extract affects yogurt's physico-chemical characteristics and antioxidant capacity.

Methods: A completely randomized design with six treatment groups (0%, 2%, 4%, 6%, 8% and 10% fruit peel extract) and triplicate samples was used. The test parameters performed were viscosity, syneresis, water holding capacity, emulsion activity index, antioxidant DPPH IC_{50} and phenolic content, with one-way ANOVA and Duncan's test ($P<0.05$) applied to analyze the differences. Fourier transform infrared spectroscopy (FTIR) was analyzed descriptively. Higher concentrations of fruit peel extract resulted in decreased viscosity and syneresis, increased water holding capacity and emulsion activity.

Result: Higher concentrations of fruit peel extract resulted in decreased viscosity and syneresis, but increased water holding capacity and emulsion activity. Antioxidant metrics showed a significant decrease in IC_{50} values and an increase in total phenolic content. The enrichment of yogurt with apple peel extract not only improved functional properties but also enhanced compositional parameters, particularly phenolic compounds such as quercetin, which were confirmed by FTIR analysis. These compositional changes were strongly correlated with the improved antioxidant activity and stability of the yogurt matrix.

Key words: Antioxidant activity, Bioactive compounds, By-product, Food fortification, Functional yogurt, Phenolic content.

INTRODUCTION

The global surge in metabolic diseases such as diabetes has spotlighted the role of diet in prevention and management strategies (Ali *et al.,* 2022; Sorrenti *et al.,* 2023). Urbanization and sedentary lifestyles have led to unhealthy eating patterns, elevating healthcare costs and reinforcing the need for functional foods enriched with bioactive compounds (Liu *et al.,* 2023; Tapia-Quirós *et al.,* 2022). Among these, apple peel, a former waste product, has emerged as a rich source of polyphenols, notably quercetin, with antioxidant and anti-inflammatory effects (Rojo-Poveda *et al.,* 2020; Sorrenti *et al.,* 2023). Its valorization also aligns with sustainability goals in the food industry, particularly when incorporated into widely consumed products like yogurt (Saraiva *et al.,* 2019).

This study explores the potential of Malus sylvestris peel extract as a yogurt fortifier, focusing on antioxidant enhancement, physicochemical characteristics, storage stability and sensory qualities. The research examines possible synergistic effects between yogurt's probiotic content and apple peel phytochemicals (Tapia-Quirós *et al.,* 2022) and aims to propose cost-effective processing methods suitable for small to medium-scale producers (Barati, 2023). It contributes to public health through the development of nutritious, appealing and sustainable food products.

Apples and their by-products, particularly the peel, are recognized as valuable sources of phenolic compounds such as quercetin, which contribute to their strong antioxidant capacity. Apples are also rich in vitamins, as well as minerals such as calcium, phosphorus and potassium and various organic acids, further supporting their use as functional ingredients in dairy products (Ali *et al.,* 2023). Apple peels, rich in flavonoids like quercetin, are known to mitigate oxidative stress, support insulin signaling and contribute to glycemic control (Ali *et al.,* 2022; Liu *et al.,* 2023). They may also enhance gut health by modulating microbiota (Rojo-Poveda *et al.,* 2020). Fermentation in yogurt can increase polyphenol bioavailability (Tapia-Quirós *et al.,* 2022),

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although stability is challenged by pH, temperature and light (Lankanayaka, 2024). Consumer acceptance further depends on maintaining optimal texture, flavor and appearance (Liu *et al.,* 2023). Despite interest, few studies comprehensively address the technical and metabolic impacts of fruit-derived inclusions in dairy.

This study uniquely investigates the integration of Malus sylvestris peel extract in yogurt, with emphasis on phenolic retention during processing and storage (Sorrenti *et al.,* 2023), including energy-efficient techniques like microwave-assisted extraction (Barati, 2023). It evaluates impacts on viscosity, color and flavor, bridging lab findings and commercial feasibility. This is especially relevant amid increasing demand for clean-label, sustainable foods (Latife-Betül and Akgün, 2023) and regulatory compliance on safety and health claims (Tapia-Quirós *et al.,* 2022).

Beyond yogurt, this work offers broader implications for food innovation and waste reduction. It reflects a multidisciplinary effort to promote metabolic health through dietary strategies (Liu *et al.,* 2023), valorize apple peel waste (Salazar-Orbea *et al.,* 2023) and balance functionality with consumer appeal (Lankanayaka, 2024). By generating robust evidence on safety, efficacy and acceptability (Rojo-Poveda *et al.,* 2020), the study supports informed decision-making across food production, regulation and public policy, public health while simultaneously contributing to public health objectives through thoughtful product development and evidence-based policy formation. Therefore, this study was designed to evaluate the effects of Malus sylvestris peel extract on the compositional and physico-chemical properties of low-fat yogurt, with particular emphasis on its antioxidant capacity and potential for functional food development.

MATERIALS AND METHODS

This section outlines the experimental design, materials, yogurt fortification procedures, analytical methods and data analysis strategies employed to investigate the effects of *Malus sylvestris* peel extract in yogurt. The methodological framework integrates established practices for evaluating bioactive compound efficacy and stability, drawing on literature related to yogurt fortification and functional ingredient optimization (Anuyahong *et al.,* 2020; Fernández *et al.,* 2022; Jooyandeh, 2024). The workflow adheres to recognized guidelines for minimizing bias and ensuring the robustness of the findings (Cenobio-Galindo *et al.,* 2019; Nazir *et al.,* 2022).

Research design

Given the multi-factor nature of yogurt fortification, a completely randomized design (CRD) was adopted, with six treatment groups: control (without the addition of extract) and incremental extract levels (2%, 4%, 6%, 8%, 10%) of *Malus sylvestris* peel extract, each comprising three replicates.

Raw materials

Skim milk was sourced from a local dairy farm, ensuring consistent compositional quality. Starter cultures containing *Lactobacillus bulgaricus*, *Streptococcus thermophilus* and *Lactobacillus acidophilus* were procured from a certified culture supplier, following guidelines recommended for probiotic-enriched yogurt products (Nazir *et al.,* 2022).

Apple peel extract

Peels of *Malus sylvestris* were separated from ripe fruits, thoroughly cleaned and dried under controlled temperature to minimize enzymatic browning (Ali *et al.,* 2022). The dried peels were ground into a fine powder to facilitate efficient extraction (Brahmi *et al.,* 2022). Preliminary studies have indicated that the peel contains a significant amount of phenolic compounds, particularly quercetin, which can confer antioxidant and anti-inflammatory benefits (Liu *et al.,* 2023).

Extraction method of apple peel extract

Microwave-assisted extraction (MAE) was employed to obtain the apple peel extract, aligning with recommendations that highlight the efficiency of MAE in recovering phenolics from agricultural by-products (Lankanayaka, 2024). Briefly, a 50% (v/v) methanol solution was used as solvent, with extraction parameters of 50°C and a total irradiation time of 12 minutes (on/off cycles). This process was adapted from prior protocols demonstrating optimal yield of polyphenols when using moderate temperatures and methanol concentrations (Flores-Mancha *et al.,* 2021). After extraction, the mixture was filtered through Whatman No. 4 paper and the solvent was evaporated using a rotary evaporator at 50°C and 55 mmHg vacuum (Cenobio-Galindo *et al.,* 2019). The resulting concentrate was stored at 4°C in an airtight container until subsequent yogurt fortification.

Yogurt preparation and fortification

Skim milk was pasteurized at 72°C for 5 minutes, consistent with standard low-temperature long-time (LTLT) processes (Nazir *et al.,* 2022). The pasteurized skim milk was then cooled to 37°C before inoculation with the starter culture at 2% (w/v). Following inoculation, the apple peel extract was added at the respective concentrations for each treatment group (0%, 2%, 4%, 6%, 8%, 10%). The mixtures were thoroughly homogenized and transferred to sterile containers for fermentation at 37°C 20 hours (Fernández *et al.,* 2022).

Upon completion of fermentation, samples were stored at 4°C for up to 48 hours to stabilize the gel structure prior to physico-chemical and antioxidant analyses (Salazar-Orbea *et al.,* 2021). The choice of cold storage conditions was informed by evidence that polyphenols may degrade at higher temperatures and that refrigeration can help preserve both sensory attributes and bioactive compound integrity (Peña, 2024).

Analytical methods

Viscosity

Measured at room temperature using a Brookfield Viscometer (L1 spindle, 100 rpm) (Saraiva *et al.,* 2019).

Three readings per sample were recorded and average values were used.

Syneresis

Evaluated by centrifuging 15 g of yogurt at 1535 rpm for 20 minutes and calculating the percentage of separated whey relative to total weight (Brahmi *et al.,* 2022).

Water holding capacity (WHC)

Determined by centrifuging 10 g of yogurt at 3000 rpm for 10 minutes, measuring the supernatant and expressing WHC as a percentage of retained water (Anuyahong *et al.,* 2020).

Emulsion activity index (EAI)

Assessed following the method (Cenobio-Galindo *et al.,* 2019), where yogurt samples were emulsified with soybean oil and diluted with 0.1% SDS solution before measuring absorbance at 500 nm.

DPPH radical scavenging assay (IC_{50})

The DPPH method was used for determining radical scavenging capacity (Ateteallah and Osman, 2019). Each yogurt sample was extracted in methanol, mixed with 0.05% DPPH and allowed to react in the dark for 30 minutes. Absorbance was recorded at 517 nm and the IC_{50} value was calculated from the inhibition curve (Flores-Mancha *et al.,* 2021).

Total phenolic content (TPC)

Measured by the Folin-ciocalteu reagent assay (Maphosa *et al.,* 2022). Aliquots of sample extracts were reacted with Folin-Ciocalteu reagent and sodium carbonate. After a 30-minute incubation at room temperature, absorbance was read at 725 nm. Gallic acid standards were used for calibration and TPC was expressed in milligrams of gallic acid equivalents per milliliter (mg GAE/mL) (Barati, 2023).

Chemical structure-fourier transform infrared spectroscopy (FTIR)

The FTIR method used (Krisnaningsih *et al.,* 2024) with slight modifications. The UV-Vis spectra were captured using a GBS UV/VIS 920 instrument. One milligram of yogurt sample was dehydrated in a vacuum desiccator. Then, it was finely ground and mixed thoroughly with 200 mg of KBr powder, dried in an oven and met the analytical reagent quality standards (Merck, DAC, USP).

Data analysis

Data from all measurements were analyzed using one-way analysis of variance (ANOVA), followed by Duncan's multiple range test at a 5% significance level ($P<0.05$) to differentiate among treatment means (Jooyandeh, 2024; Maphosa *et al.,* 2022). Statistical analyses were conducted using SPSS software (IBM SPSS Statistics, Version 25) and results were expressed as mean ± standard deviation. In addition, data obtained from fourier transform infrared spectroscopy (FTIR) were evaluated descriptively to characterize the functional groups and chemical interactions present in the fortified yogurt samples.

RESULTS AND DISCUSSION

The following sections present the outcomes of fortifying yogurt with different concentrations of *Malus sylvestris* peel extract, focusing on the physico-chemical properties, emulsion-related parameters and antioxidant activities. The result of the research is shown in Table 1.

Viscosity

The addition of *Malus sylvestris* peel extract to yogurt resulted in a concentration-dependent decrease in viscosity, with the control group (0%) showing 646.67±5.77 cPs and the highest value observed at 1% extract (T1: 676.67 cPs), followed by a progressive decline as extract levels increased, particularly at 8% and 10%, where viscosity dropped below 600 cPs (Table 1). This trend suggests that higher concentrations of extract may disrupt the protein network or dilute milk solids, weakening the gel structure. These results contrast with previous reports using Spirulina platensis or corn milk, which enhanced yogurt viscosity due to their polysaccharide and protein content (Ahmed, 2024; Ateteallah *et al.,* 2022). The differing outcomes may be attributed to compositional differences, since some

Table 1: The result of physico-chemical yogurt fortified by *Malus sylvestris* peel extract.

Treatments	Viscosity (cPs) ± SD	Syneresis (%) ± SD	Water holding capacity (%) ± SD	Emulsion activity index (%) ± SD	Antioxidant activity IC_{50} (mg/ml) ± SD	Phenolic content (mg/ml) ± SD
T0	646.67^{f}±5.77	43.05^{e}±0.46	54.02^{a}±3.10	74.37^{a}±0.14	342.87^{f}±3.73	422.78^{a}±0.40
T1	676.67^{e}±5.77	42.43^{d}±0.12	56.48^{a}±0.39	83.67^{b}±0.03	280.48^{e}±0.39	481.38^{b}±0.72
T2	656.67^{d}±5.77	39.45^{c}±0.14	60.32^{b}±0.62	87.01^{c}±0.11	267.78^{d}±0.81	522.73^{c}±3.79
T3	623.33^{c}±5.77	39.06^{c}±0.15	60.53^{b}±0.39	89.21^{d}±0.32	181.37^{c}±1.51	526.05^{c}±0.53
T4	610.00^{b}±5.74	38.23^{b}±0.10	60.67^{b}±0.37	89.72^{d}±0.09	169.99^{b}±0.76	582.77^{d}±0.52
T5	596.67^{a}±5.77	37.21^{a}±0.02	61.50^{b}±0.17	90.49^{e}±0.62	160.88^{a}±0.92	632.09^{e}±2.67

Note: Different uppercase letters in the column indicated a significant effect ($P<0.05$).

T0: Control (without *Malus sylvestris* peel extract); T1: Addition with 2% of *Malus sylvestris* peel extract; T2: Addition with 4% of *Malus sylvestris* peel extract; T3: Addition with 6% of *Malus sylvestris* peel extract; T4: Addition with 8% of *Malus sylvestris* peel extract; T5: Addition with 10% of *Malus sylvestris* peel extract.

polysaccharides are known to enhance viscosity (Ateteallah and Osman, 2019), whereas phenolic-rich extracts such as apple peel may interact with dairy proteins in a way that reduces gel strength. Moreover, phenolic compounds from *Malus sylvestris* peel extract may interfere with casein micelle aggregation, thereby decreasing viscosity despite the milk base containing moderate fat (3.2%) and protein (3.3%) levels (Nair *et al.,* 2019).

When compared with yogurt fortified with pomegranate peel extract, as reported by Bakhti *et al.* (2025), a different pattern was observed. In that study, viscosity consistently increased with extract addition, reaching peak values at day 15 of storage (10 mg: 769.63 cPs; 20 mg: 764.06 cPs; 30 mg: 753.80 cPs), followed by slight reductions or stabilization on day 21. The discrepancy between Malus sylvestris and Punica granatum fortification may reflect the distinct phenolic profiles of these fruit by-products. While pomegranate peel phenolics likely reinforce the casein network through electrostatic interactions that improve matrix resistance, high levels of *Malus sylvestris peel extract* phenolics may cause over-crosslinking or protein precipitation, yielding a less homogeneous gel and consequently lower viscosity. Nevertheless, the decline in viscosity with higher Malus sylvestris concentrations was accompanied by improved water-holding capacity (54.02%-61.50%) and reduced syneresis, indicating that gel stability was maintained even as apparent thickness decreased. Thus, Malus sylvestris peel extract primarily enhances yogurt stability, whereas pomegranate peel extract is more effective in improving texture and thickness (Bakhti *et al.,* 2025).

Syneresis

Syneresis, defined as the spontaneous separation of whey from the yogurt gel in the absence of any external force, is a critical quality attribute that must be carefully controlled, especially during product storage (Zahir *et al.,* 2024). In this study, syneresis, measured as whey separation percentage, showed a significant inverse relationship with Malus sylvestris peel extract concentration (Table 1). The control group exhibited the highest syneresis at 43.05± 0.46%, while samples fortified with 8% and 10% extract showed a marked reduction, reaching 37.21±0.02% ($P<0.05$). This suggests enhanced gel stability and water-holding capacity with increasing extract levels, consistent with previous findings on the role of added solids and phenolic compounds in improving yogurt texture (Ateteallah and Osman, 2019). The reduced syneresis is likely due to phenolic-protein interactions and the addition of total solids, which reinforce the protein matrix through additional cross-links (Ateteallah *et al.,* 2022). Similar effects have been reported with spirulina, corn milk and other plant-based fortifiers rich in polysaccharides or proteins (Ahmed and Saddam, 2024). Moreover, phenolic compounds in the extract may help stabilize the gel, as seen in other dairy systems (Flores-Mancha *et al.,* 2021) and their synergy with casein micelles plays a key role in enhancing water retention despite decreased viscosity, supporting conclusions drawn in related studies on fermented dairy product stability (Rako *et al.,* 2019).

When compared with previous work by Ogunyemi *et al.* (2021), who reported syneresis values of 53.33-65.33% in yogurts fortified with African black pepper, turmeric and clove extracts, the values obtained in the *Malus sylvestris* peel extract fortified yogurts were considerably lower, ranging only from 37-43%. In their study, turmeric supplementation most effectively reduced syneresis among the spice-based treatments, but its effect remained less pronounced compared to the fortification with Malus sylvestris. The superior performance of *Malus sylvestris* peel extract can be attributed to its high phenolic content (422.78-632.09 mg/mL), which promotes stronger protein-polyphenol interactions, leading to a more compact gel matrix and higher water-holding capacity (54.02%-61.50%). This dual effect of enhanced antioxidant activity and improved gel stability highlights the advantage of Malus sylvestris as a fortifier, offering not only functional health benefits but also superior physical stability and sensory quality compared to spice-enriched yogurts (Ogunyemi *et al.,* 2021).

Water holding capacity

Water holding capacity (WHC) exhibited a trend similar to syneresis, with control samples showing the lowest value (54.02±3.10%) and fortified yogurts displaying a progressive increase in WHC as *Malus sylvestris* peel extract concentration rose (Table 1). The 10% extract treatment reached 61.50±0.17%, a significant improvement ($P<0.05$) compared to the control. This enhancement supports existing literature that phenolic compounds and added solids strengthen protein-water and protein-protein interactions, reinforcing the gel matrix's ability to retain moisture (Peña, 2024; Ateteallah and Osman, 2019). Such interactions help reduce syneresis and improve yogurt texture, aligning with findings on bioactive-rich plant extract fortification (Atetallah *et al.,* 2022).

Although not the primary focus, pH and titratable acidity values across all treatments remained within normal ranges (pH 4.3-4.6), indicating that fermentation was not significantly disrupted. This aligns with prior studies showing that moderate phenolic fortification does not markedly affect acid production in yogurt (Jooyandeh, 2024). The resilience of lactic acid bacteria under these conditions may explain the consistent acid profiles, reinforcing that extract incorporation at studied levels can improve textural qualities without compromising fermentation dynamics.

Emulsion activity index

The emulsion activity index (EAI) increased significantly ($P<0.05$) with higher concentrations of Malus sylvestris peel extract, from 74.37±0.14% in the control to 90.49±0.62% at 10% extract (Table 1). This enhancement indicates improved emulsion stability, aligning with studies that show plant-derived compounds can enhance emulsifying properties in dairy matrices (Cenobio-Galindo *et al.,* 2019; Chen *et al.,* 2020). Phenolic compounds, although not protein-rich, exhibit

amphiphilic behavior that reduces interfacial tension and may synergize with dairy proteins to stabilize emulsions (Maphosa *et al.,* 2022). The formation of phenolic-protein complexes also contributes to reinforcing interfacial layers, thereby supporting long-term emulsion stability (Nair *et al.,* 2019).

These findings are consistent with previous reports on plant-based fortification improving emulsion activity in dairy products. For instance, flaxseed and cactus pear extracts enhanced emulsion stability through interactions among phenolics, proteins and fat globules (Drozłowska *et al.,* 2020; Cenobio-Galindo *et al.,* 2019). However, absolute values may vary across studies due to differences in plant type, extraction solvents and molecular compositionas observed with encapsulated beet extracts (Flores-Mancha *et al.,* 2021). Thus, while the trend of improved emulsion activity index holds true, the extent of enhancement depends on extract concentration and its compatibility with the dairy matrix. Similar effects were also documented in yogurt systems fortified with corn milk and turmeric, which showed that phenolic compounds and plant metabolites can modify interfacial interactions, thereby influencing the final emulsion stability (Atetallah *et al.,* 2022; Britto *et al.,* 2020). Collectively, these reports support the present findings that phenolic-protein interactions are crucial in reinforcing interfacial layers and promoting long-term emulsion stability in fortified dairy products.

Antioxidant activity

As shown in Table 1, the antioxidant activity of yogurt fortified with *Malus sylvestris* peel extract increased significantly ($P<0.05$) with higher extract concentrations, indicating a strong contribution of phenolic compounds to the overall antioxidant potential. The control yogurt, prepared without apple peel extract, exhibited an IC_{50} value of 342.87± 3.73 mg/mL, reflecting the limited antioxidant activity typical of yogurt lacking phenolic enrichment. In sharp contrast, fortification with 10% extract reduced the IC_{50} to approximately 160.88±0.92 mg/mL, signifying a major improvement in radical scavenging potential ($P<0.05$). Intermediate extract levels (2-8%) showed a gradual decrease in IC_{50}, implying dose-dependent antioxidant activity.

These data align with previous research that underscores the capacity of phenolic compounds in apple peel to scavenge free radicals and mitigate oxidative stress (Ali *et al.,* 2022). The link between quercetin, abundant in apple peels and enhanced antioxidant capacity has been corroborated in multiple studies examining fruit-derived phenolics in dairy matrices (Nascimento, 2023). By binding to or neutralizing reactive oxygen species, these phenolics may offer protective benefits, potentially relevant for consumers seeking functional foods with health-promoting properties (Sorrenti *et al.,* 2023).

The notable decrease in IC_{50} across treatments with rising extract concentrations complements the trends observed for other plant-based fortifications, such as anthocyanin-rich extracts from riceberry rice (Anuyahong *et al.,* 2020) or grape skin polyphenols (Fernández *et al.,* 2022). These parallel findings reinforce the broad conclusion that yogurt serves as an effective vehicle for delivering antioxidative bioactive compounds.

Total phenolic content

The total phenolic content (TPC) of yogurt increased significantly with the incorporation of Malus sylvestris peel extract, demonstrating a clear dose-dependent enhancement. The highest TPC was recorded at 10% extract concentration, reaching 632.09±2.67 mg GAE/L, in contrast to the control sample which contained only 422.78±0.40 mg GAE/L. This enhancement in TPC was strongly correlated with antioxidant activity ($R^2>0.90$), highlighting the role of phenolic compounds in radical scavenging (Flores-Mancha *et al.,* 2021; Tapia-Quirós *et al.,* 2022). In line with previous studies, these compounds also offer anti-inflammatory benefits and support the functional valorization of fruit by-products (Rojo-Poveda *et al.,* 2020; Barati, 2023; Liu *et al.,* 2023). A significant positive correlation between TPC and emulsion activity index ($r\approx0.85$) suggests enhanced emulsifying properties due to the amphiphilic nature of phenolics (Drozłowska *et al.,* 2020), while a moderate negative correlation with viscosity ($r\approx-0.60$) may indicate partial disruption of the protein matrix (Gharibzahedi and Altýntas *et al.,* 2022). Protein–polyphenol interactions may stabilize phenolics yet weaken gel structure (Nair *et al.,* 2019; Salazar-Orbea *et al.,* 2023), although improved WHC and reduced syneresis (Ateteallah and Osman, 2019) help mitigate textural issues. Emulsion stability was also enhanced, likely due to polyphenols contributing to interfacial layer formation (Maphosa *et al.,* 2022).

These results align with studies noting both beneficial and compromising effects of plant-based fortification on yogurt properties (Jaman *et al.,* 2022; Ahmed and Saddam, 2024). Improved WHC and gel strength corroborate previous findings that phenolics can reinforce dairy matrices (Atetallah *et al.,* 2022; Jooyandeh, 2024), while increased EAI confirms their stabilizing potential even in phenolic-dominant extracts (Cenobio-Galindo *et al.,* 2019). The overall antioxidant improvement supports the utilization of fruit peel by-products like grape or apple skins for value-added functional food development (Rojo-Poveda *et al.,* 2020; García-Gurrola *et al.,* 2019; Barati, 2023). In a study on watermelon peel and rind from different cultivation areas in Indonesia, Priastomo *et al.* (2024) found that the total flavonoid content (TFC) was usually higher in the peel than in the rind. However, this trend was not observed in all regions, indicating that growing area and environmental conditions may affect the distribution and concentration of flavonoids. Nonetheless, minor textural compromises, the need for sensory validation and considerations of phenolic bioavailability remain important for future research and formulation optimization (Britto *et al.,* 2020).

Chemical structure-fourier transform infrared spectroscopy

Characteristic testing of apple peel extract yogurt (*Malus sylvestris*) was carried out using the fourier transform

infrared spectroscopy (FTIR) technique, which aims to identify functional groups in the sample and ensure the chemical composition and concentration of active compounds contained therein. The FTIR technique works by measuring infrared absorption by molecules in a sample at various wavelengths so that it can provide information about the types of chemical bonds and molecular structures of compounds contained in apple peel extract.

The results of FTIR test on various treatments (T0-T5) showed variations in wavelength indicating the presence of various group functions. Fig 1 shows peaks in the IR spectrum ranging from 1050-1300 cm^{-1}, indicating the presence of C-O groups in alcohols, ethers, carboxylic acids and esters. The peak at 648 cm^{-1} indicates the aromatic C-H bending group. The 879-871 cm^{-1} contains C-H bending flavonoids and polyphenols, indicating the presence of active compounds from the flavonoid group. In addition, the C-O-C glycosidic group of polysaccharides was found at a wavelength of 927-925 cm^{-1}, which is related to polysaccharides in the sample. C-H bending of aromatic compounds and flavonoids was found at 1317 cm^{-1}, further confirming the presence of bioactive compounds from the flavonoid group. Higher spectrum, there is a peak at 2308 cm^{-1} related to C≡N nitrile indicating the possible presence of compounds containing nitrile groups. The range of 2872-2773 cm^{-1} has absorption indicating carboxylic acid O-H with hydrogen bonds, which is related to the presence of carboxylic acid. C-H stretching of lipids appears at 2875-2929 cm^{-1}, indicating the presence of fat or lipids in the extract and the peak of 3128 cm^{-1} which is related to O-H stretching of amines, indicating the presence of amine groups.

Fig 1 and Table 2 show that the flavonoid compound quercetin in apple peel extract can still be detected in yogurt

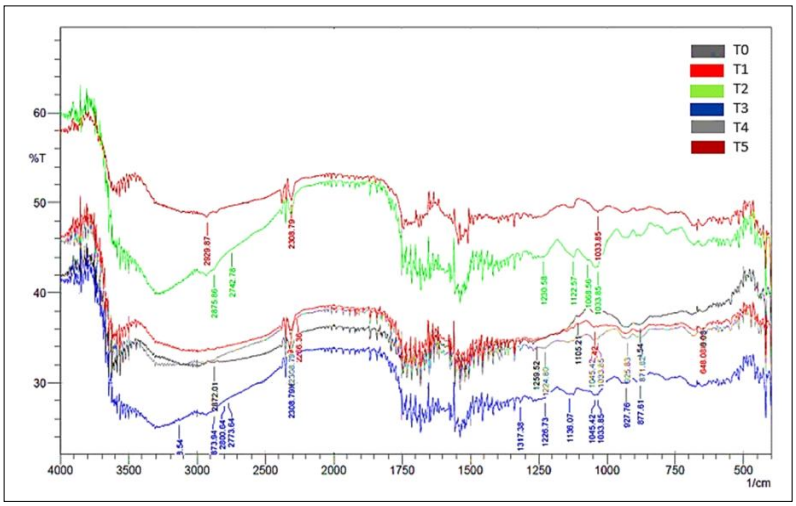


Fig 1: Fourier transform infrared spectroscopy (FTIR) of yoghurt fortified with *Malus sylvestris* fruit peel extract.

Table 2: Functional group yogurt fortified with *Malus sylvestris* fruit peel extract.

Treatment						Group	Chemical structure
T0	T1	T2	T3	T4	T5		
648.08	648.08					C-H	Aromatic
879.54			877.61	871.82		C-H	Flavonoid, Poliphenol
			927.76	925.83		C-O-C	Glikosidik Polisakarida
1105.21	1045.42	1033.85	1033.85	1033.85	1033.85	C-O	Flavonoid, alcohol
1259.52		1068.56	1045.42	1045.42		C-O	Dilatation Vibration
		1122.57	1136.07			C-O	Ester, Eter
		1230.58	1226.73	1224.8		C-O	Stretching Ester
			1317.38			C-H	Aromatic, flavonoid
	2266.36					C≡N	Nitril
2308.79	2308.79		2308.79	2308.79	2308.79	C≡N	Nitril
2872.01		2742.78	2773.64			O-H	Carboxylic hydrogen bond
		2875.86	2800.64			C-H	Stretching lipid
			2873.94		2929.87	C-H	Stretching lipid
			3128.54			O-H	Strectchingamina

with the addition of apple peel extract through the FTIR test. Quercetin is an active compound responsible for the pharmacological effects of plants that can be identified through FTIR analysis, which reveals functional groups such as phenolic groups (OH), carbonyl groups (C = O), aromatic C-H groups, C-O groups and aromatic C = C groups, even in the presence of quercetin. The peak at 3200-3600 cm^{-1} points to the O-H group associated with phenol and hydrogen bonds (Krisnaningsih *et al.,* 2024). Flavonoids are bioactive compounds found in large quantities in plants and play an important role in secondary metabolism. This compound has a broad spectrum of biological activity (Pawlikowska-Pawlêga *et al.,* 2014). The interaction of protein and fat in yogurt can cause changes in intensity or spectrum shifts, quercetin remains relatively stable in the yogurt matrix. This shows that the antioxidant potential and biological activity of quercetin can still be maintained in the final product.

CONCLUSION

Higher concentrations of the extract decreased viscosity but notably reduced syneresis and increased total phenolic content, thereby underscoring a promising trade-off between functional benefits and textural quality. The findings also highlight the role of protein-phenolic interactions, through which phenolics can bind with dairy proteins to form a more stable gel matrix. The best treatment in this study was the addition of 10% apple peel (*Malus sylvestris*) extract, which resulted in a viscosity of 596.67 cPs, a syneresis value of 37.21, a water holding capacity of 61.50%, an emulsion activity index of 90.49%, an antioxidant activity (IC_{50}) of 160.88 mg/ml and a phenolic content of 632.09 mg/ml.The use of apple peel extract is not only effective in improving the texture stability of products but also provides significant functional benefits, making it a strong recommendation for application in the food industry.

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Disclaimers

The authors declare that the findings and opinions expressed in this manuscript are entirely their own and do not represent those of their affiliated institutions or the funding body.

Informed consent

Informed consent was not required for this study as it did not involve any human subjects or animal testing.

Conflict of interest

The authors declare no conflict of interest.

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