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Extraction, Characterisation and Utilisation of Bioactive Compounds from Date Fruit

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Date fruit (*Phoenix dactylifera* L.), known for its rich bioactive compounds, was the focus of this study, which aimed to optimize microwave-assisted extraction (MAE) methods for isolating these compounds and developing fortified milk with added date syrup. The research evaluated total phenolic content (TPC) and total flavonoid content (TFC) under varying microwave frequencies, extraction times, and plant-to-solvent ratios. Date fruits were procured, cleaned, processed into powder, and subjected to various MAE conditions, with standard spectrophotometric methods used to quantify TPC and TFC. Optimal extraction conditions for maximum TPC (37±1.1 mg GAE/g) and TFC (460±0.6 mg QE/g) were identified at a microwave frequency of 720 W, an extraction time of 5 minutes, and a plant-to-solvent ratio of 1:15, highlighting the significant influence of microwave power and extraction time on phenolic and flavonoid contents. Furthermore, the research explored the nutritional enhancement of milk through fortification with date syrup, assessing the fortified milk

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for total soluble solids (TSS), pH, TPC, and TFC, which demonstrated an improved nutritional profile. This research provides valuable insights into the MAE of date fruits and the potential of date syrup in developing functional food products, guiding future studies and industrial applications aimed at enhancing the nutritional and functional properties of food products.

Keywords: Bioactive compounds; microwave-assisted extraction; sustainability; date fruit; fortified milk.

1. INTRODUCTION

The date palm (*Phoenix dactylifera* L.) has long been a symbol of resilience, nourishment, and cultural significance, playing a pivotal role in the sustenance of communities across arid regions for millennia [1]. Known as the "Tree of Life" in various ancient civilizations, the date palm continues to be a vital agricultural resource, particularly for its highly valued fruit [2,3]. This research delves into the advanced methodologies for extracting and characterizing bioactive compounds from date fruit, aiming to harness these compounds to enhance the nutritional profiles of food products through fortification, with a particular emphasis on the utilization of microwave-assisted extraction (MAE) techniques.

The cultivation of date palms dates back thousands of years, with archaeological evidence pointing to their consumption as early as 6000 BCE [4]. Originating from the Middle East, the cultivation of this resilient species has since spread across continents, thriving in regions characterized by arid and semi-arid climates [5]. Today, major producers such as Egypt, Saudi Arabia, Iran, and Algeria dominate the global date fruit market, contributing significantly to the availability of this nutritious fruit [3].

Date fruit is renowned for its rich chemical composition, encompassing a broad spectrum of macronutrients, micronutrients, and bioactive compounds [6]. These include carbohydrates, primarily in the form of sugars like glucose and fructose, essential vitamins, minerals, and dietary fibers [7]. However, it is the presence of bioactive compounds—such as phenolic compounds, flavonoids, carotenoids, and tocopherols—that elevates the date fruit to the status of a functional food with potent antioxidant and health-promoting properties [8]. This study seeks to expand the scientific understanding of these bioactive compounds, particularly in the context of their extraction and application in developing functional foods.

The significance of date fruit extends beyond its sugar content, with nutritional profiles revealing an average protein concentration ranging from 1.22% to 3.30%, lipids from 0.11% to 7.33%, ash content from 1.43% to 6.20%, and carbohydrates from 65.7% to 88.02%. Notably, variations in these components are influenced by factors such as cultivar type and ripening stage [9,10]. Additionally, date fruits are a source of essential amino acids and B-complex vitamins, contributing to their nutritional density (Golshan et al., 2017).

The extraction of bioactive compounds from date fruit is crucial for harnessing its full nutritional and medicinal potential [11]. Among the various extraction techniques, MAE stands out for its efficiency and sustainability. By utilizing microwave energy to facilitate the release of bioactive compounds from plant matrices, MAE offers distinct advantages, including reduced extraction time, lower solvent consumption, and enhanced extraction yields [12]. This research advances the field by optimizing MAE techniques to maximize the yield and quality of bioactive compounds from date fruit, providing a foundation for their application in developing functional foods.

Incorporating these bioactive compounds into food matrices, such as milk, represents a promising approach to fortifying nutritional profiles and enhancing functional properties. By enriching milk with date-derived bioactives, this study aims to create a fortified beverage with enhanced antioxidant, vitamin, and mineral content, thus addressing contemporary nutritional challenges and promoting human health.

In summary, this research contributes to the scientific community by advancing the methodologies for bioactive compound extraction from date fruit and exploring their potential applications in functional food development. The study's rigorous approach, encompassing optimized extraction techniques, comprehensive chemical analysis, and thorough sensory

evaluation, ensures the reliability and robustness of the findings. This work not only deepens the understanding of date fruit bioactives but also paves the way for innovative applications in the food industry, reinforcing the scientific validity and novelty of the research presented in this manuscript.

2. MATERIALS AND METHODS

2.1 Materials

Fresh date fruits were sourced from the agricultural store of Lovely Professional University. Aluminum chloride ($AlCl_3$) (98% pure), sodium hydroxide (NaOH) (97% pure), sodium nitrite ($NaNO_3$) (98% pure), and sodium carbonate (Na_2CO_3) (99.5% pure) were supplied by LOBA Chemie Pvt. Ltd. Gallic acid (98% pure) and quercetin (99% pure) were procured from Sigma-Aldrich in India. The Folin-Ciocalteu reagent (FCR) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) (98% pure), along with ethanol (C_2H_5OH) (95% pure), were also provided by LOBA Chemie Pvt. Ltd., India. Distilled water (DI) was obtained from Lovely Professional University.

2.2 Sample Preparation

Drying fruit before conducting experiments, particularly for extraction purposes, is essential for several reasons. First, it concentrates bioactive compounds, thereby enhancing extraction efficiency and yielding higher quantities of the desired phytochemicals. Additionally, drying inhibits microbial growth and enzymatic activity, both of which could otherwise degrade these compounds. This preservation is vital for maintaining the nutritional and functional properties of the fruit, ensuring accurate and reproducible experimental results [13].

For this study, date fruits (Phoenix dactylifera L.) were sourced from the Agricultural Store at Lovely Professional University. The fruits were thoroughly washed with tap water to remove surface impurities and were manually deseeded. To facilitate grinding, the fruits were soaked in water overnight at room temperature to soften the flesh. After softening, the fruits were ground into a paste, and excess water was carefully absorbed using a filtration setup designed to prevent contamination. Specifically, a layer of muslin cloth was placed over the paste, followed by filter paper, and then another layer of muslin cloth on top. This indirect contact method minimized the risk of contamination by preventing direct contact between the paste and the filter paper. The semi-dried pulp was then transferred to a Sunray Tray Dryer model 998, set at 60°C, and dried until completely moisture-free. The dried pulp was subsequently ground into a fine powder using a laboratory grinder. The resulting date fruit powder (DFP) was stored in zip-lock bags, which were then placed in airtight LDPE containers to maintain freshness and prevent moisture absorption. This meticulous preparation method ensured the production of high-quality DFP, with its nutritional properties well-preserved, making it suitable for further analysis and various applications. Microwave-assisted extraction (MAE) was then performed by placing a measured amount of date powder (DP) along with a specified quantity of water into a 100 mL beaker.

2.3 Physico-Chemical Analysis of DPC

The physicochemical analysis of moisture content, ash content, protein, and fat content was determined using the standard procedure of AOAC [14]. Apart from these factors the TPC and TFC of DFP was also analyzed using the Folin–Ciocalteu method and $AlCl_3$ method respectively as described by Tharasena & Lawan [15].

2.4 Microwave-Assisted Extraction (MAE) of DFP

The MAE method described by Mostafa et al. [16] was adapted with slight modifications. The solid-to-solvent ratios were set at 1:15, 1:20, and 1:25 w/v, and a microwave (LG-ZX-031S) was used at four different power settings: 180 W, 360 W, 540 W, and 720 W, with treatment times of 3 and 5 minutes. The resulting DSP solutions were centrifuged at 6000 RPM for 15 minutes. The water extracts were then filtered using Whatman No. 4 filter paper, and the remaining residues were oven-dried at 70°C. All samples were stored at -20°C until further use.

2.5 Total Phenolic Content (TPC)

The total phenolic content (TPC) of the DFP extract was evaluated using a modified version of the Folin–Ciocalteu method as described by Tharasena & Lawan [15]. In this procedure, 1 mL of Folin–Ciocalteu reagent (FCR) was combined with 1 mL of the aqueous DFP extract, and the mixture was vortexed. After 5 minutes, 10 mL of a 7% Na_2CO_3 solution was added, and the mixture was left to sit for 90 minutes. The absorbance was then measured at 750 nm using a UV spectrophotometer (Systronics AU-2701).

The TPC was expressed in terms of gallic acid equivalents (GAE, mg gallic acid/g of sample), calculated using a calibration curve created with standard gallic acid.

2.6 Total Flavonoid Content (TFC)

The total flavonoid content (TFC) of the raw date fruit powder (DFP) extract was assessed following the $AlCl_3$ method described by Tharasena & Lawan [15]. Briefly, 1 mL of the filtered DFP extracts was mixed with 4 mL of distilled water and vortexed. Next, 0.3 mL of a 5% $NaNO_2$ solution was added, and the mixture was vortexed for an additional 5 minutes. Following this, 0.3 mL of a 10% $AlCl_3$ solution was introduced, and the mixture was vortexed for 6 minutes. Afterward, 2 mL of 1 M NaOH was added, and the solution was vortexed again. The final solution, which had a total volume of 10 mL, was left to stand for 30 minutes at room temperature in a dark environment. The absorbance of the mixture was then recorded at 517 nm. The TFC of the sample was expressed as milligrams of quercetin equivalents (QE) per gram of fresh sample (mg/g sample), based on a quercetin calibration curve.

2.7 Fourier Transform Infrared Radiation (FTIR) Analysis of DFP Extract

Properties of the extract with optimized parameters are carried out for FTIR analysis spectroscopy was used to analyze the FTIR spectrum of the extract (Shimadzu IRAffinity-1). The extract was placed in direct contact with diamond crystal cell Attenuated Total Reflectance crystal cell. MAE of bioactive compounds from date fruits at optimised parameters (720 W; 1:20 sample to water ratio; 5 min) are carried out. These extracts are used to analyse the properties of the date fruit sample obtained by MAE.

2.8 Preparation of Bioactive Fortified Milk

Microwave-assisted extraction (MAE) of bioactive compounds from date fruits was conducted under optimized conditions (720 W; 1:20 sample-to-water ratio; 5 minutes). These extracts were then incorporated into milk to enhance its nutritional profile. The preparation of date extract-enriched milk followed the method suggested by Palthur et al. [17] for ginger-flavoured milk, with slight modifications.

To create date-flavoured bioactive fortified milk, various concentrations of date extract—15%, 25%, and 35%—were prepared and incorporated into the milk. The samples were homogenized, sweetened with 4% cane sugar, and filled into 250 mL sterilized glass bottles. The bottles were then pasteurized at 161°F for 16 minutes, cooled, and stored in a refrigerator at 5-10°C. The samples were subsequently analyzed for chemical parameters such as pH, total soluble solids (TSS), total phenolic content (TPC), and total flavonoid content (TFC). Additionally, the milk was evaluated organoleptically for color, appearance, aroma, consistency, sweetness, and overall acceptability. The results for each parameter are presented in tables and have been statistically analyzed and discussed.

2.9 Statistical Analysis

All extraction experiments and analytical measurements were conducted in triplicate. Statistical analysis was carried out using Minitab software. The data were analyzed using analysis of variance (ANOVA) to assess significance ($P < 0.05$), followed by Tukey's multiple comparison test to identify significant differences.

3. RESULT AND DISCUSSION

3.1 Physio-Chemical Analysis of DFP and DFP Extract

The physicochemical properties of *Phoenix dactylifera* L. were evaluated through a series of analyses. The moisture content of the DFPwas determined to be 4%, 3.5%, and 5.8%, using the method outlined by AOAC [14]. This low moisture content is beneficial as it reduces the risk of microbial growth and enzymatic degradation, thus enhancing the powder's stability and safety. Manickavasagan et al. [18] also observed that the moisture content in spray-dried date powder varies between 1.5% and 6.1%, indicating that experimental variables significantly impact moisture levels. The total ash value of the DFP, determined according to AOAC [15], was found to be 1.5%, 2.0%, and 2.5%. This ash content reflects the mineral composition of the fruit, with higher values indicating greater mineral concentrations, which are essential for various physiological functions. El-Sharnouby et al. [19] reported ash content ranging from 2.92% to 3.60% in dried date fruits, highlighting a broader range of mineral content across different samples.

The crude fat content, measured using AOAC [15] Method No. 920-39, was 1.7±0.1%. Awan et al. [20] reported fat contents for Dhaki, Aseel, and Zahidi dates as 1.28±0.04%, 2.61±0.08%,

and 2.08±0.07%, respectively, showcasing variability in fat content among different date varieties. Protein content, assessed using the Kjeldahl method as per AOAC [15], ranged from 2.5% to 3.5%. This aligns with the findings of El-Sohaimy & Hafez [21], who noted a protein content of approximately 3% in date fruit. This consistency emphasizes the significance of protein content in nutritional assessments.

The TPC determined using the Folin-Ciocalteu method, with results indicating 19±1.7 mg GAE/100 g before MAE and ranging from 29±5.3 to 37±1.1 mg GAE/100 g after extraction. Phenolic compounds are vital for their health benefits, including disease prevention. Mansouri et al. [22] reported TPC values ranging from 2.49 to 8.36 mg GAE/100 g FW in Algerian date fruits, while Biglari et al. [23] found values between 2.89 and 141.35 mg GAE/100 g DW in Iranian dates. These variations highlight the influence of factors such as cultivar, environmental conditions, and extraction techniques on phenolic content.

TFC assessed using the AlCl3 method, with results of 38±12.5 mg QE/g before extraction and ranging from 45±0.6 to 460±0.6 mg QE/g post-extraction. Flavonoids contribute to various health benefits, including antioxidant properties. Biglari et al. [23] reported TFC ranging from 1.62 to 81.79 mg CEQ/100 g DW in Iranian dates, while Benmeddour et al. [24] observed TFC values from 15.22 to 299.74 mg QE/100 g DW in Algerian dates. These discrepancies underscore how cultivar types, environmental factors, fruit maturity, moisture content, and extraction methods can affect flavonoid content.

Table 1. Proximate and phytochemical composition of *Phoenix dactylifera* L.

Moisture (%)	4.40±1.10
Total ash (g)	2.00±0.40
Protein (%)	3.00±0.40
Fat (%)	1.7±0.1
Total phenolic content (mg GAE/g)	19±1.7
Total flavonoid content (mg QE/G)	38±12.5

Table 2. TPC and TFC of MAE of date fruit

Sl. No.	Microwave frequency (W)	Time (Min)	Ratio (P:S)	TPC	TFC
1.	180	3	1:15	$29±5.3^{bcd}$	$81 ±4.8^{k}$
2.			1:20	$30±3.7^{bcd}$	$52 ±1.9^{o}$
3.			1:25	$31±0.4^{bc}$	$45 ±0.6^{p}$
4.	180	5	1:15	$31±0.5^{bc}$	$231 ±1.2^{h}$
5.			1:20	$30±0.1^{bcd}$	$309 ±1.2^{d}$
6.			1:25	$21±0.1^{e}$	$460 ±0.6^{a}$
7.	360	3	1:15	$32±6^{bc}$	$81 ±3.5^{k}$
8.			1:20	$32±3.7^{bc}$	$62 ±0.6^{n}$
9.			1:25	$33±0.2^{b}$	$55 ±0.6^{o}$
10.	360	5	1:15	$33±3.7^{b}$	$132 ±1.2^{j}$
11.			1:20	$36±1.4^{a}$	$225 ±1.2^{h}$
12.			1:25	$31±0.1^{bc}$	$251 ±1.2^{g}$
13.	540	3	1:15	$36±0.3^{a}$	$86 ±1.6^{k}$
14.			1:20	$36±0.2^{a}$	$89 ±0.6^{k}$
15.			1:25	$33±0.1^{b}$	$72 ±0.6^{m}$
16.	540	5	1:15	$34±2.8^{ab}$	$95 ±0.6^{k}$
17.			1:20	$36 ±1.1^{a}$	$146 ±1.2^{i}$
18.			1:25	$31 ±0.1^{bc}$	$191 ±17^{h}$
19.	720	3	1:15	$36 ±0.4^{a}$	$108 ±0.6^{j}$
20.			1:20	$36 ±0.3^{a}$	$105 ±0.6^{j}$
21.			1:25	$36 ±0.1^{a}$	$115 ±0.6^{i}$
22.	720	5	1:15	$37 ±1.1^{a}$	$158 ±1.2^{i}$
23.			1:20	$37 ±0.1^{a}$	$198 ±1.2^{h}$
24.			1:25	$34 ±0.1^{ab}$	$214 ±1.2^{h}$

Values are mean in triplicates ± standard deviation.

3.2 FTIR Analysis of DFP Extract

FTIR analysis of the date fruit extract obtained from MAE revealed a diverse array of functional groups, indicating a complex chemical profile. The peak at 1622.71 cm^{-1}, corresponding to C=C bond stretching in conjugated alkenes, suggests the presence of antioxidant-rich compounds. Additionally, the peak at 516.67 cm^{-1}, associated with C-Br stretching in halo compounds, points to the presence of halogenated substances. Other significant peaks include C-O stretching in primary alcohols, ethers, and esters, as well as C-H stretching in alkanes, which indicate the presence of various bioactive compounds such as sugars, lipids, and organic acids. The detection of N-H stretching in amines and O-H stretching in alcohols and carboxylic acids highlights the presence of nitrogen-containing compounds and organic acids. Furthermore, the S=O stretching observed in sulfates and sulfonyl chlorides suggests the presence of sulfur-containing compounds with potential antioxidant and antimicrobial properties. Overall, the FTIR results underscore the extract's potential as a rich source of bioactive compounds with diverse health benefits, paving the way for the development of functional foods or nutraceuticals from date fruits.

3.3 Sensory analysis of bioactive fortified milk

The sensory evaluation of date milk, enriched with varying concentrations of bioactive compounds from date fruit, revealed notable improvements in sensory attributes compared to the control milk. The evaluation parameters included color and appearance, aroma, consistency, sweetness, and overall acceptability, assessed using a 9-point hedonic scale.

The results indicated that the color and appearance of the date milk progressively enhanced with increasing proportions of the date fruit extract. Specifically, Sample 3, which contained 35% bioactive compound, achieved the highest score of 9 ± 0, signifying an extreme preference by the panelists. In contrast, the control milk received a score of 7 ± 0.79. This improvement in color and appearance is visually supported by the radar graph,

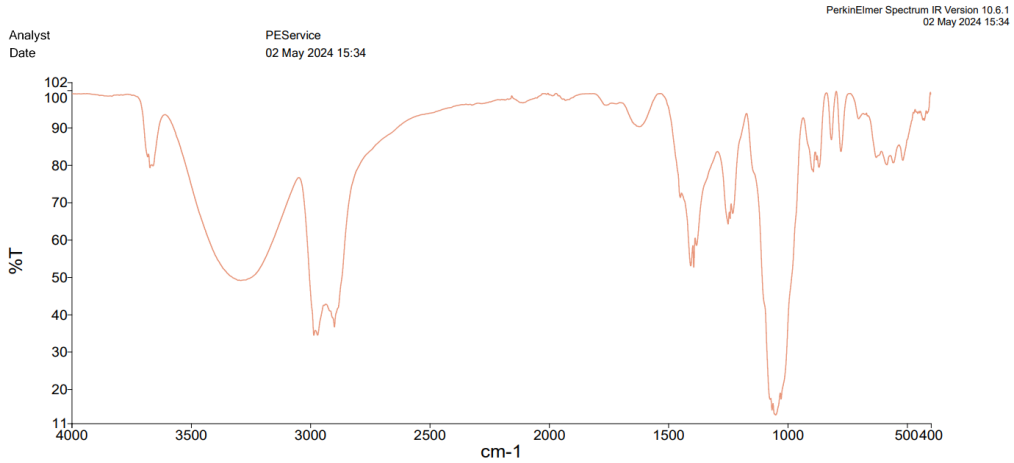

Fig. 1. FTIR analysis of DFP extract

Table 3. Sensory evaluation of milk fortified with date bioactive extract using 9-point hedonic scale

Parameters	Control	Sample 1 (15%)	Sample 2 (25%)	Sample 3 (35%)
Colour and Appearance	7 ± 0.79^{d}	7.7 ± 0.45^{c}	8 ± 0.45^{b}	9 ± 0^{a}
Aroma	6 ± 0.79^{d}	6.7 ± 0.45^{c}	7 ± 0.45^{b}	8.5 ± 0.5^{a}
Consistency	5 ± 0.79^{d}	5.7 ± 0.45^{c}	6 ± 0.45^{b}	7.5 ± 0.5^{a}
Sweetness	7.9 ± 0.66^{d}	8 ± 0^{c}	8 ± 0.49^{b}	9 ± 0^{a}
Overall	6.3 ± 0.8^{d}	6.7 ± 0.4^{c}	7.6 ± 0.45^{b}	9 ± 0^{a}

Values are mean in triplicates ± standard deviation.

which illustrates the superior scores for Sample 3 across all sensory attributes compared to the control and other samples. Similarly, the aroma of the date milk improved with higher concentrations of the date fruit extract. Sample 3 received the highest aroma score of 8.5 ± 0.5, while the control sample had a lower score of 6 ± 0.79. The radar graph demonstrates this trend, with Sample 3 standing out significantly in terms of aroma compared to the control and lower-concentration samples. Consistency scores also showed a positive correlation with the concentration of date fruit extract. Sample 3 was rated 7.5 ± 0.5 for consistency, whereas the control sample was rated 5 ± 0.79. The radar graph corroborates this finding, indicating a progressive improvement in consistency with higher extract concentrations. Sweetness was another parameter that saw significant enhancement with increasing extract concentration. Sample 3 received a score of 9 ± 0 for sweetness, compared to the control's 7.9 ± 0.66. The radar graph reflects this trend, highlighting the substantial increase in sweetness scores for Sample 3. Overall acceptability, a composite measure of all sensory attributes, was highest for Sample 3, which received a score of 9 ± 0. The control milk scored 6.3 ± 0.8, indicating a marked preference for the higher concentration date milk. The radar graph illustrates this comprehensive preference, with Sample 3 significantly outperforming the control and other samples in overall acceptability.

These findings are consistent with previous research, which has documented the sensory benefits of incorporating bioactive compounds from date fruit into food products [25]. The improvements in color, aroma, consistency, sweetness, and overall acceptability with increased concentrations of date fruit extract suggest that date milk can be developed as a functional beverage with enhanced sensory and nutritional properties.

3.4 Physio-chemical Analysis Of Date Bioactive Fortified Milk

The physicochemical analysis of date milk fortified with date bioactive extract demonstrated significant variations in pH, total soluble solids (TSS), TPC, and TFC compared to the control milk, as detailed in Table .

The pH values of the fortified milk samples ranged from 7.1 to 7.1, showing minimal variation from the control sample's pH of 6.9 ± 0. This indicates that the incorporation of date fruit extract did not significantly alter the acidity levels of the milk. The control sample had the lowest pH, while all fortified samples exhibited the same, slightly higher pH of 7.1 ± 0.

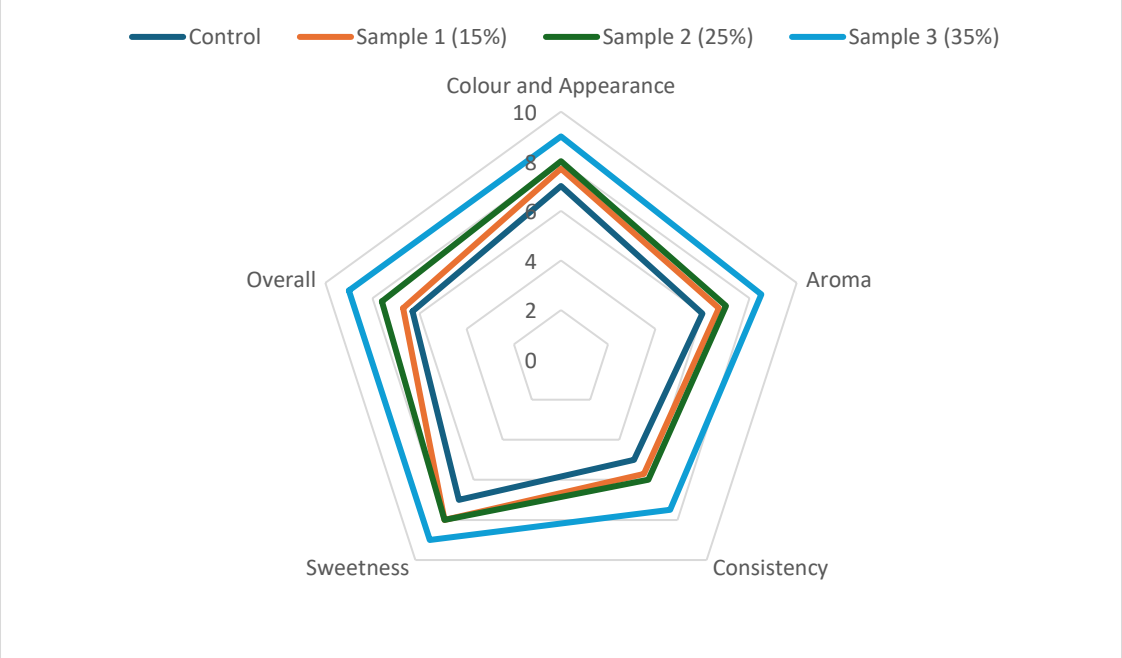

Fig. 2. Radar Graph of Sensory Analysis

Table 4. The physio-chemical characters of developed milk fortified with date bioactive extract

	Control	Sample 1 (15% Date Bioactive Extract)	Sample 2 (25% Date Bioactive Extract)	Sample 3 (35% Date Bioactive Extract)
pH	6.9±0^{b}	7.1±0^{a}	7.1±0^{a}	7.1±0^{a}
TSS	12.7±0.7^{c}	14.2±0^{b}	13.5±0.4^{bc}	16.1±0.4^{a}
TPC	133±2.9^{c}	147±4.7^{b}	152±5.2^{bc}	190±4.8^{a}
TFC	656±6.1^{cd}	689±60^{c}	842±47^{b}	933±56^{a}

Values are mean in triplicates ± standard deviation.

TSS values ranged from 12.7 ± 0.7 in the control sample to 16.1 ± 0.4 in Sample 3, with the highest TSS observed in the milk containing 35% date bioactive extract. This increase in TSS with higher concentrations of date extract indicates a higher concentration of dissolved solids, which may contribute to the enhanced sweetness and overall flavor profile. The lowest TSS was recorded in the control sample, highlighting the impact of the date extract on the milk's soluble solid content.

The TPC values ranged from 133 ± 2.9 mg GAE/100 g in the control sample to 190 ± 4.8 mg GAE/100 g in Sample 3, with the highest phenolic content found in the milk with 35% date bioactive extract. This increase reflects the contribution of date fruit's bioactive compounds to the phenolic content, which is known for its antioxidant properties. The control sample had the lowest TPC, emphasizing the significant impact of date extract on enhancing the phenolic content of the milk. TFC values ranged from 656 ± 6.1 mg QE/g in the control to 933 ± 56 mg QE/g in Sample 3, with the highest flavonoid content found in the milk with 35% date bioactive extract. This increase signifies a higher concentration of flavonoids, which are associated with various health benefits. The control sample had the lowest TFC, indicating the substantial enrichment of flavonoids in the fortified milk. The increase in TPC and TFC in the fortified milk samples, particularly in Sample 3, underscores the successful incorporation of bioactive compounds from date fruit. These compounds are recognized for their antioxidant properties and potential health benefits, which likely contribute to the observed improvements in sensory attributes and overall acceptability of the date milk samples [25]. The relatively stable pH values suggest that the incorporation of date fruit extract had minimal impact on the milk's acidity, while the significant increases in TSS, TPC, and TFC levels highlight the benefits of higher bioactive compound concentrations. In conclusion, the addition of date fruit extract to milk not only enhanced its sensory attributes but also improved its nutritional profile, especially at higher concentrations. Sample 3, with 35% date bioactive extract, emerged as the most preferred variant, showcasing its potential as a functional beverage with superior sensory and nutritional qualities [26-31].

4. CONCLUSION

This research underscores the substantial potential of date fruit as a rich source of bioactive compounds, particularly total phenolic content (TPC) and total flavonoid content (TFC). Utilizing microwave-assisted extraction (MAE), these compounds were effectively extracted under optimized conditions, thereby demonstrating the technique's efficacy in maximizing yield. The incorporation of these bioactive extracts into milk significantly enhanced its nutritional profile, as evidenced by both sensory and physicochemical evaluations.

The proximate analysis of date powder revealed considerable quantities of moisture, total ash, protein, fat, TPC, and TFC, highlighting its nutritional value. The optimization of MAE parameters—such as microwave frequency, extraction time, and the plant-to-solvent ratio—was pivotal in achieving the highest recovery of TPC and TFC, underscoring the importance of precise extraction conditions. Sensory evaluations of the fortified milk revealed notable improvements in color, aroma, consistency, sweetness, and overall acceptability with increasing concentrations of the date extract. These sensory enhancements were corroborated by physicochemical analyses, which demonstrated stable pH levels alongside increased total soluble solids (TSS), TPC, and TFC in the fortified milk, indicating successful integration of the bioactive compounds.

In conclusion, this study highlights the potential of date fruit as a valuable source of bioactive compounds and validates the effectiveness of optimized extraction techniques. The enrichment of milk with these extracts presents a promising

approach for developing functional food products with enhanced nutritional benefits. Furthermore, the observed variability in nutrient content across different date varieties suggests significant opportunities for the innovation of dietary products and the improved utilization of these valuable nutrients.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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