**Original Research Article**

# EXTRACTION, CHARECTERISATION AND UTILIDATION OF BIOACTIVE COMPOUNDS FROM DATE FRUIT


## 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 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.) stands as asymbol of resilience, nourishment, and cultural significance, spanning millennia of human history (Jain & Johnson 2015). Revered as the "Tree of Life" in various ancient civilizations, the date palm has been integral to the sustenance and prosperity of communities across arid regions (Zohary & Hopf 2000). Beyond its historical and cultural importance, the date palm remains a pivotal agricultural resource, particularly in producing its prized fruit (FAOSTAT 2021). This research article delves into the extraction, characterization, and utilization of bioactive compounds from date fruit, focusing on enhancing food nutritional profiles through fortification, with specific emphasis on the utilization of MAE techniques.

Dating back thousands of years, the cultivation of date palms has been intertwined with human civilization, with evidence of its consumption found in archaeological sites dating back to 6000 BCE (Sallon et al., 2008). Originating in the Middle East, the date palm's cultivation has spread across continents, finding a home in regions characterized by arid and semi-arid climates (Zohary et al., 2012). Today, major producers of dates, as reported by the Food and Agriculture Organization (FAO), include countries such as Egypt, Saudi Arabia, Iran, and Algeria, with each contributing significantly to the global date fruit market.

Date fruit, the succulent and nutritious yield of the date palm, boasts a rich chemical composition, encompassing a spectrum of macronutrients, micronutrients, and bioactive compounds (Al-Farsi & Lee 2008). Comprising primarily carbohydrates, including sugars such as glucose and fructose, date fruit also contains essential vitamins, minerals, and dietary Fibers (Al-Shahib & Marshall 2003). However, it is the presence of bioactive compounds that elevates date fruit to a superfood status (Rahmani et al., 2014). Among these bioactive compounds, phenolic compounds, flavonoids, carotenoids, and tocopherols stand out for their potent antioxidant and health-promoting properties (Vayalil 2012).

Date palm fruits, scientifically referred to as *Phoenix dactylifera* L, are widely recognized for their nutritional density, establishing them as a crucial component of a balanced diet. Their significant sugar content, predominantly consisting of glucose, fructose, and sucrose, serves as a quick and easily accessible energy source (Maqsood et al., 2020). Variations in sugar composition are observed among different cultivars, with the Khalas cultivar notably high in glucose and fructose, while Deglet, Noor, Sukkary, and Nabtat cultivars 14 exhibit abundance in sucrose. The sugar concentration increases as dates ripen, influenced by factors such as cultivation conditions and cultivar type (Malek et al., 2020).

Apart from their sweet taste, dates are renowned for their nutritional richness. They boast 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 spanning from 65.7% to 88.02%. However, protein levels decrease during non-enzymatic browning and tannin precipitation phases. Dates contain both essential and non-essential amino acids, including glutamic acid, alanine, lysine, aspartic acid, serine, glycine, and proline. While dates have a moderate fat content (0.2-0.5%), they are rich in B-complex vitamins (Golshan et al., 2017).

The extraction of bioactive compounds from date fruit presents a crucial step in harnessing its nutritional and medicinal potential (Barreira et al., (2010). Various extraction techniques have been employed, ranging from conventional methods such as Soxhlet extraction and maceration to modern approaches like ultrasound-assisted extraction, microwave-assisted extraction, pulsed electric field extraction and supercritical fluid extraction (Chemat&Cravotto 2012). However, one emerging method that has garnered attention for its efficiency and sustainability is MAE (Luque-García & de Castro 2004). By utilizing microwave energy to facilitate the release of bioactive compounds from plant matrices, MAE offers several advantages, including reduced extraction time, lower solvent consumption, and enhanced extraction yields (Rostagno et al., 2007).

In the context of extracting bioactive compounds from date fruit, MAE holds immense promise (Wang et al., 2008). The application of microwave energy enables rapid and selective heating of the sample, promoting the rupture of cell walls and facilitating the release of intracellular compounds (Périno-Issartier et al., 2011). Moreover, the controlled heating process minimizes heat-sensitive compounds' thermal degradation, preserving the extracted constituents' integrity and bioactivity (Mourtzinos& Kalogeropoulos 2015). With its ability to enhance extraction efficiency while minimizing environmental impact, MAE emerges as a sustainable and cost-effective alternative to traditional extraction methods (Rostagno et al., 2007).

One notable application of extracted bioactive compounds from date fruit lies in their incorporation into food matrices to fortify nutritional profiles and enhance functional properties. In this study, we focus on fortifying milk with date bioactive, aiming to enrich this staple beverage with antioxidants, vitamins, and minerals derived from date fruit. By blending date bioactive into milk formulations, we seek to enhance its nutritional value and impart desirable sensory attributes, thereby widening its consumer appeal.

In summary, the extraction, characterization, and utilization of bioactive compounds from date fruit represent a burgeoning field with immense potential for applications in food, pharmaceuticals, and nutraceuticals. Through advancements in extraction technologies, such as MAE, we can unlock the full spectrum of bioactive compounds harboured within date fruit, harnessing their health-promoting properties to fortify and enhance the nutritional profiles of various food products. As we delve deeper into the biochemistry and functionality of date fruit bioactive, we pave the way for innovative solutions to address nutritional challenges and promote human health and well-being.

## 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 nitrite ($NaNO_2$) (98% pure), sodium hydroxide (NaOH) (97% pure), and sodium carbonate ($Na_2CO_3$) (99.5% pure) were supplied by LOBA ChemiePvt. 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 ChemiePvt. Ltd., India. Distilled water (DI) was obtained from Lovely Professional University.

### *2.2 Sample preparation*

Drying fruit prior to experiments, particularly for extraction, is crucial for several reasons. It concentrates bioactive compounds, improving extraction efficiency and yielding higher amounts of desired phytochemicals. Additionally, drying inhibits microbial growth and enzyme activity that could degrade these compounds, preserving the fruit's nutritional and functional properties for storage and later analysis. This preservation is essential for obtaining accurate and reproducible experimental results (Aziz et al., 2012).

For this study, date fruits (*Phoenix dactylifera* L.) were obtained from the Agricultural Store at Lovely Professional University. The fruits were thoroughly washed with tap water to eliminate surface impurities and manually deseeded. To aid the grinding process, the fruits were soaked in water overnight at room temperature to soften the flesh. The softened fruits were then ground into a paste, with excess water absorbed using filter papers. The semi-dried pulp was transferred to a tray dryerof model Sunray Tray Dryer 998  set at 60°C and dried until completely moisture-free. The dried pulp was then ground into a fine powder using a laboratory grinder. The resulting date fruit powder (DFP) was stored in zip-lock bags, which were placed in airtight LDPE containers to maintain freshness and prevent moisture absorption. This careful preparation method ensured the production of high-quality DFP with preserved nutritional properties, ready for further analysis and various applications.The MAE was then performed by adding a specific quantity of DP along with the appropriate amount of water in 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 (2005). Apart from these factors the TPC and TFC of DFP was also analyzedusing the Folin–Ciocalteu method and $AlCl_3$ method respectively as described by Tharasena& Lawan (2014).

*2.4 Microwave-assisted extraction (MAE) of DFP*

The MAE method described by Mostafa et al. (2022b) 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 TPC of  DFP extract was determined using a modified Folin–Ciocalteu method (Tharasena& Lawan, 2014). Briefly, 1 mL of FCR was mixed with 1 mL of aqueous extracts of DFP, and the mixture was vortexed. After 5 minutes, 10 mL of 7% $Na_2CO_3$ solution was added, and the mixture was allowed to sit for 90 minutes. The absorbance of the sample was then measured at 750 nm using a UV spectrophotometer (Systronics AU-2701). The data was represented in gallic acid equivalents (GAE, mg gallic acid/g of sample), using a calibration curve generated with standard gallic acid.

*2.6 Total flavonoid content (TFC)*

The TFC of the raw DFP extract was determined using the $AlCl_3$ method (Tharasena& Lawan, 2014). In brief, 1 mL of filtered DFP extracts were diluted with 4 mL of distilled water and vortexed. Subsequently, 0.3 mL of a 5% $NaNO_2$ solution was added, and the mixture was vortexed for another 5 minutes. Then, 0.3 mL of 10% $AlCl_3$ was added, and the mixture was vortexed for 6 minutes. Following this, 2 mL of 1 M NaOH was added to the solution and vortexed. The resulting solution, with a total volume of 10 mL, was left to stand for 30 minutes at ambient temperature in a dark environment. The absorbance of the mixture was then measured at 517 nm. The TF content of the sample was calculated as mg of quercetin equivalents (QE) per gram of fresh weight of sample (mg/g sample), using a calibration curve prepared with quercetin.

*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*

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 incorporated into milk to enhance their nutritional profile. DFP extract-incorporated milk was prepared as per the method suggested by Palthur et al., (2014) for the preparation of ginger flavoured milk with slight modification.

For the preparation of date-flavored bioactive fortified milk, different 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 then filled into 250 ml sterilized glass bottles. They were pasteurized at 161°F for 16 minutes, cooled, and stored in a refrigerator at 5-10°C. The samples were subsequently analyzed for various chemical parameters, including pH, total soluble solids (TSS), TPC, and 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.

*2.9Statistical 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*

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 |

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 (2005). 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. (2015) 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 theDFP, determined according to AOAC (2005), 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. (2007) 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 (2005) Method No. 920-39, was 1.7±0.1%. Awan et al. (2018) 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 (2005), ranged from 2.5% to 3.5%. This aligns with the findings of El-Sohaimy& Hafez (2010), 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 MAEand 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. (2005) reported TPC values ranging from 2.49 to 8.36 mg GAE/100 g FW in Algerian date fruits, while Biglari et al. (2008) 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.

TFCassessed 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. (2008) reported TFC ranging from 1.62 to 81.79 mg CEQ/100 g DW in Iranian dates, while Benmeddour et al. (2013) 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 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*

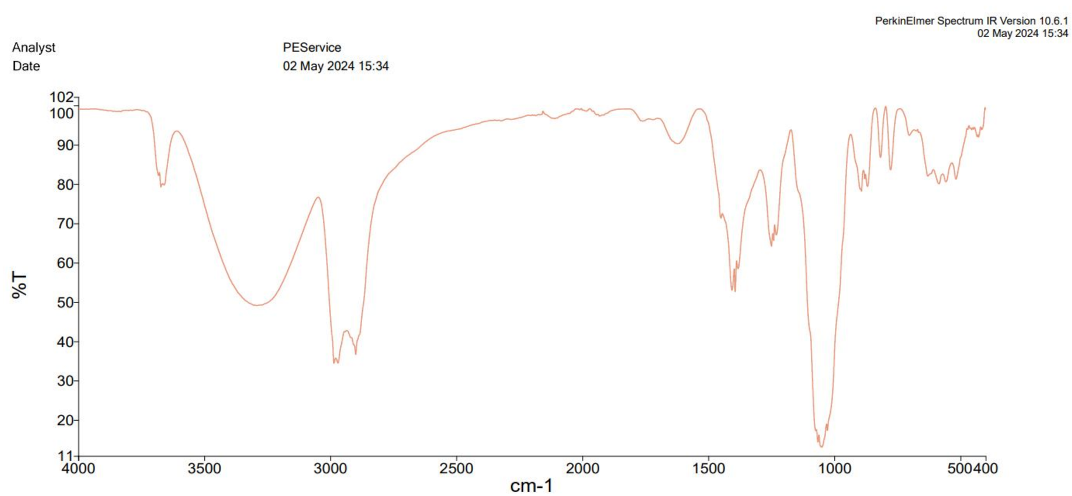


Fig:1 FTIR analysis of DFP extract

FTIR analysis of the date fruit extract from MAE identified a range of functional groups, reflecting a complex chemical profile. The peak at 1622.71 $cm^{-1}$, indicating C=C bond stretching in conjugated alkenes, points to the presence of antioxidant-rich compounds. Conversely, the peak at 516.67 $cm^{-1}$, associated with C-Br stretching in halo compounds, suggests the presence of halogenated substances. Additional significant peaks include C-O stretching in primary alcohols, ethers, and esters, and C-H stretching in alkanes, revealing a variety of bioactive compounds such as sugars, lipids, and organic acids. Peaks for N-H stretching in amines and O-H stretching in alcohols and carboxylic acids highlight nitrogen-containing compounds and organic acids. The detection of S=O stretching in sulphates and sulfonyl chloride indicates the presence of sulphur-containing compounds with potential antioxidant and antimicrobial properties. Overall, the FTIR results emphasize the extract's potential as a source of bioactive compounds with diverse health benefits, suggesting avenues for developing functional foods or nutraceuticals from date fruits.

*3.3 Sensory analysis of bioactive fortified milk*

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.



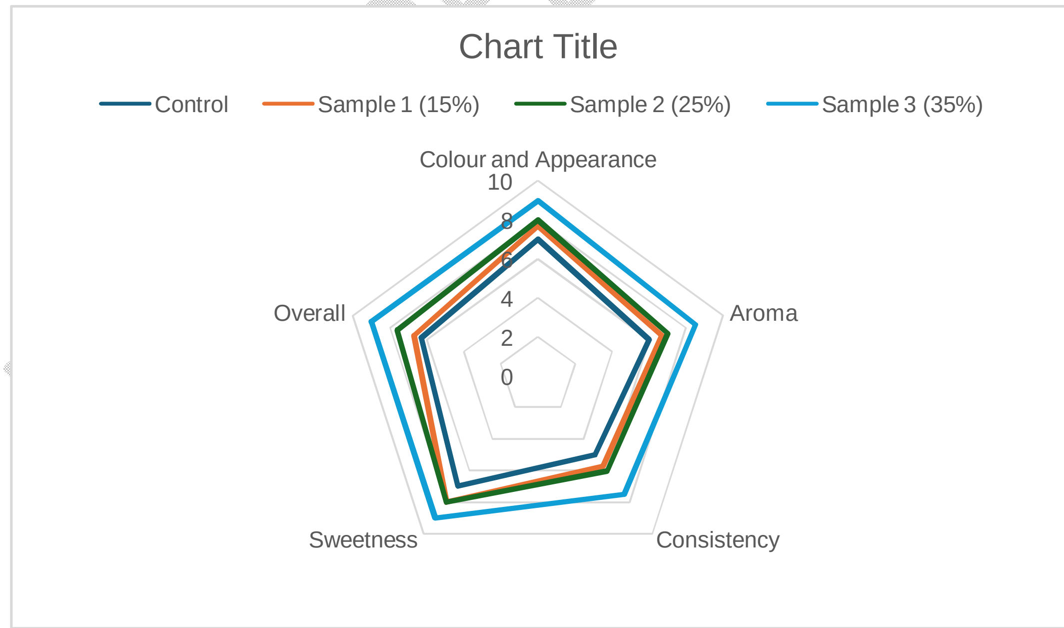


Figure 2: Radar Graph of Sensory Analysis

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, 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 (Kaur et al., 2015). 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.

*3.3 Physio-chemical analysis of date bioactive fortified milk*

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** | $6.9\pm0^{b}$ | $7.1\pm0^{a}$ | $7.1\pm0^{a}$ | $7.1\pm0^{a}$ |
| **TSS** | $12.7\pm0.7^{c}$ | $14.2\pm0^{b}$ | $13.5\pm0.4^{bc}$ | $16.1\pm0.4^{a}$ |

| | | | | |
|---|---|---|---|---|
| **TPC** | $133\pm2.9^{c}$ | $147\pm4.7^{b}$ | $152\pm5.2^{bc}$ | $190\pm4.8^{a}$ |
| **TFC** | $656\pm6.1^{cd}$ | $689\pm60^{c}$ | $842\pm47^{b}$ | $933\pm56^{a}$ |

Values are mean in triplicates ± standard deviation.

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.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 (Kaur et al., 2015). 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.

**4.Conclusion**

The research underscores the significant potential of date fruit as a source of bioactive compounds, notably TPC and TFC. Through the application of MAE, these compounds were efficiently extracted under optimized conditions, highlighting the effectiveness of this technique in maximizing yield. The incorporation of these bioactive extracts into milk has demonstrated a marked enhancement in its nutritional profile, as evidenced by both sensory and physico-chemical evaluations.

The proximate analysis of date waste powder revealed substantial amounts of moisture, total ash, protein, fat, TPC, and TFC, indicating its considerable nutritional value. Optimization of MAE parameters, including microwave frequency, extraction time, and plant-to-solvent ratio, facilitated the highest recovery of TPC and TFC, emphasizing the critical role of precise extraction conditions.Sensory evaluation of the fortified milk showed improvements across several attributes, including color, aroma, consistency, sweetness, and overall acceptability, with increasing concentrations of the date extract. The physicochemical analysis corroborated these findings, with stable pH levels and increased TSS, TPC, and TFC in the fortified milk, reflecting the successful incorporation of bioactive compounds.

In conclusion, this study highlights the potential of date fruit as a rich source of bioactive compounds and demonstrates the effectiveness of optimized extraction techniques. The enrichment of milk with these extracts offers a promising strategy for developing functional food products with enhanced nutritional benefits. The observed variability in nutrient content among different date varieties further suggests opportunities for innovative dietary products and improved utilization of these valuable nutrients.

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