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Functional Dates Production Enriched with Low-Roasted Full Date Seed Powder: A Sustainable Approach to Dates By-Product Valorization

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Abstract

The date palm industry generates substantial seed waste representing an underutilized resource rich in dietary fiber, bioactive compounds, and natural antioxidants. Currently, these seeds are predominantly discarded or utilized as low-value livestock feed. This study investigated the chemical composition, phenolic content, and flavonoid profiles of date seeds from the Saidy cultivar and evaluated the development of novel functional dates by incorporating low-roasted full date seed powder (LRFDSP) into pitted fruits. Chemical analysis revealed date seeds as a significant source of dietary fiber (74-80% dry weight), crude fat (10-13%), crude protein (5-6%), and ash (0.9-1.8%). The Saidy variety demonstrated notable carbohydrate content and substantial phenolic compound concentrations, indicating strong potential for food fortification applications. Fortification with LRFDSP at levels of 0.8 g and 1.6 g per fruit significantly enhanced the fiber content (from 3.00% to 12.29%) and antioxidant potential (total phenolics increased from 275.93 to 495.96 mg GAE/100g DWB) while maintaining acceptable sensory characteristics. Sensory evaluation demonstrated improved appearance, flavor, and overall acceptability scores with increasing fortification levels. This approach offers a sustainable strategy for repurposing date seed waste, creating value-added functional foods with enhanced nutritional properties. The developed functional dates represent a promising solution for both waste management and the growing consumer demand for natural, fiber-rich foods.

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1. Introduction

The date palm (*Phoenix dactylifera* L.) holds significant socioeconomic and nutritional importance, particularly in arid and semi-arid regions worldwide. Date fruits are recognized for their high carbohydrate content, essential vitamins, and minerals, forming a dietary staple with documented medicinal properties (Saleh et al., 2011). However, a critical challenge within the date industry is the sustainable management of processing by-products, notably the seeds (pits), which constitute 10-15% of the fruit's total mass (Bouaziz et al., 2010).

While date pulp serves as a valuable source of readily available carbohydrates, it contains relatively low levels of dietary fiber. Conversely, date seeds represent a concentrated source of dietary fiber and phenolic compounds, presenting significant opportunities for valorization. These inherent antioxidant properties position date seeds as potential low-cost sources of natural antioxidants for functional food applications (Park et al., 2009).

Increased dietary fiber intake has been associated with reduced risk of several chronic diseases, including cardiovascular disease, type 2 diabetes, and certain cancers (Hejri Zarifi et al., 2021). Therefore, incorporating date seeds into food products could contribute significantly to dietary fiber intake while addressing waste management challenges.

The growing consumer demand for health-promoting foods has intensified research into incorporating bioactive components and dietary fiber into novel food formulations. Date seeds, rich in these compounds, present a cost-effective agricultural by-product for this purpose. However, the substantial annual volume of date seed production often results in disposal challenges and environmental concerns. Despite their valuable composition, including carbohydrates, oils, and natural antioxidants, date seeds remain largely underutilized.

This research addresses this gap by exploring the potential of date seeds as functional food ingredients. Specifically, the study investigates the chemical composition and bioactive compound content of date seeds and evaluates the sensory attributes of functional dates fortified with low-roasted full date seed powder (LRFDSP). This approach seeks to create value-added functional foods while providing sustainable solutions for date seed waste management.

2. Materials and Methods

2.1 Materials

2.1.1 Date Samples

Mature dates of the Saidy cultivar, the predominant variety in Egypt's New Valley Governorate, were obtained at the Tamr stage (freedom of defects or physical injury) from a local processing facility in El Kharga Oasis. Upon arrival, dates were washed with distilled water to remove contaminants, and damaged fruits were discarded. A representative sample of 30 dates was randomly selected for physicochemical analysis. Dates were classified on a size basis to 1) small of size or light, 2) moderate of size, and 3) jumbo or large of size. All dates were harvested at full color.

2.1.2 Chemicals and Reagents

All chemicals for physicochemical analysis were obtained from EL-Gomhouria Trading Chemicals and Drugs Co. (Assiut, Egypt) and were of analytical grade.

2.2 Sample Preparation

2.2.1 Low-Roasted Full Date Seed Powder (LRFDSP) Preparation

Date seeds were manually separated from pulp and thoroughly washed with tap water to remove residual pulp. Following the method of Warnasih et al. (2019), cleaned seeds were air-dried at 50°C until surface moisture was completely removed. Seeds were then lightly roasted in a natural convection oven (Memmert UN, Schwabach, Germany) at 120°C for 20 minutes until achieving a light brown color. After cooling to room temperature, roasted seeds were ground using a hammer mill (Perten 120, Finland) fitted with an 80 µm mesh. The resulting powder was stored in sealed polyethylene bags under ambient conditions.

2.2.2 Functional Date Preparation

Jumbo-grade (large-size) pitted dates were fortified with LRFDSP at three different levels:

- **D1:** Jumbo-weight dates (JWD*) + 0.00 g LRFDSP per fruit as a control.
- **D2:** JWD + 0.80 g LRFDSP per fruit.
- **D3:** JWD + 1.60 g LRFDSP per fruit.

2.3 Analytical Methods

2.3.1 Physical Properties

Date samples (4 kg total) were sorted into three size categories: small, medium, and jumbo. Fruit number per kilogram was determined for each category. Twenty-five fruits from each size group were randomly selected, individually weighed, and pitted. Whole fruit, flesh, and pit weights were recorded, and flesh-to-pit ratios were calculated following Iqbal (2004).

2.3.2 Proximate Composition

Raw materials and fortified date samples were analyzed for moisture, total carbohydrates, reducing and non-reducing sugars, crude protein, ash, crude fat, and crude fiber using AOAC (2019) methods and ICUMSA (1994) guidelines.

2.3.3 Mineral Analysis

Sodium, potassium, and calcium concentrations were measured using flame photometry (Gallenkamp FGA 330, England). Iron, manganese, and magnesium were determined using atomic absorption spectrophotometry (Perkin Elmer Model 80, England) following AOAC (2019) procedures.

2.3.4 Phytochemical Analysis

Polyphenol Extraction: Polyphenols were extracted by homogenizing 50 g of pitted date flesh or date seed powder in 150 mL of boiling 80% ethanol for 15 minutes. The mixture was blended for 10 minutes, filtered, and the process repeated three times with fresh solvent. Combined filtrates were concentrated by ethanol evaporation, and final volume was adjusted to 100 mL with water (Maier & Metzler, 1965).

Carotenoid Extraction: Date seed powder (5 g) was stirred with 20 mL acetone at 4°C in darkness for 2 hours (1000 rpm). The mixture was centrifuged (4000 rpm, 10 min, 4°C), and the extract was partitioned into petroleum ether. Saponification was performed using 40% KOH in methanol at 25°C for 2 hours, followed by centrifugation (8000 rpm, 30 min, 4°C). The supernatant was dried under nitrogen and stored at −20°C. Total carotenoids were quantified at 450 nm using β-carotene calibration curves (Moo-Huchin et al., 2017).

Total Flavonoid Content: Flavonoid levels were measured using the aluminum chloride colorimetric method (Ardestani & Yazdanparast, 2007). Extracts were combined with $NaNO_2$, $AlCl_3$, and NaOH, incubated in darkness for 15 minutes, and absorbance was recorded at 510 nm using (+)-catechin as reference standard.

Tannin Content: Tannin concentration was determined using a modified vanillin-HCl assay (Broadhurst & Jones, 1978). Extracts were reacted with 4% vanillin in methanol and concentrated HCl, incubated for 15 minutes, and absorbance was measured at 500 nm with catechin as standard.

2.3.5 Sensory Evaluation

Sensory analysis was conducted on fortified date samples two days post-treatment. A trained panel of ten evaluators (faculty and graduate students from the Food Science and Technology Department, New Valley University) assessed appearance, taste, flavor, and overall acceptability using a 10-point hedonic scale according to AOAC (2019) guidelines.

2.3.6 Statistical Analysis

Data were processed using Microsoft Excel 2019. Descriptive statistics were computed and analyzed following Montgomery (2010). Analysis of variance (ANOVA) was applied to test for significant differences among treatment means, with post-hoc comparisons performed using appropriate tests. Statistical significance was set at $p < 0.05$.

3. Results and Discussion

3.1 Physical Properties of Saidy Cultivar Dates on a size basis.

Table 1 presents the physical characteristics of Saidy cultivar dates categorized by weight. Small dates exhibited the highest fruit number per kilogram (205.00), highest pit percentage (23.58%), and slightly higher pH value (6.41). Conversely, jumbo dates showed the lowest fruit number per kilogram (82.00), lowest pit percentage (13.36%), and slightly lower pH (6.40). These variations reflect differences in fruit development and concentration of molecular components.

Jumbo dates displayed superior fruit weight (12.20 g), flesh weight (10.68 g), flesh percentage (86.72%), and flesh-to-pit ratio (6.49), while small dates showed the lowest values for these parameters. These differences in physical properties among date grades are influenced by agricultural practices and environmental conditions, highlighting the importance of physical evaluations for quality assessment and industry grading (Mohammed, 2018).

Table 1. Physical Properties of Saidy Cultivar Dates on a Size Basis.

Property	Dates on a Size Basis		
	Small	Moderate	Jumbo
Fruits per kg	205.00^{a}	108.00^{b}	82.00^{c}
Fruit weight (g)	4.88^{c}	9.26^{b}	12.20^{a}
Flesh weight (g)	3.73^{c}	7.92^{b}	10.68^{a}
Pit weight (g)	1.15^{c}	1.34^{b}	1.63^{a}
Flesh/pit ratio	3.24^{c}	5.89^{b}	6.49^{a}
Flesh (%)	76.42^{c}	85.52^{b}	86.72^{a}
Pit (%)	23.58^{a}	14.51^{b}	13.36^{c}
pH value	6.41	6.40	6.40

Values in the same row with different superscripts are significantly different ($p < 0.05$)

3.2 Chemical Composition and Nutritional Properties of Saidy Cultivar Dates (on a size basis) and LRFDSP .

3.2.1 Proximate Composition

Data in Table 2 presents the proximate composition of different grades of Saidy cultivar dates and LRFDSP on a dry weight basis. Small dates exhibited the lowest moisture content (15.22%), while jumbo dates contained the highest (17.35%). These results align with Samouni (2017), who reported moisture contents ranging from 13.98 to 15.72% in date fruits.

Jumbo dates demonstrated the highest levels of non-reducing sugars (3.73%), crude fiber (3.00%), crude lipids (1.47%), ash (2.45%), and crude protein (2.41%). The LRFDSP exhibited a distinct composition profile: 5.47% moisture, 6.67% crude protein, 8.11% crude lipids, 74.27% crude fiber, 83.66% total carbohydrates, and 1.55% ash, with a pH of 5.82. These findings are consistent with previous studies by Shalaby et al. (2017).

3.2.2 Mineral Content

LRFDSP and different grades of Saidy dates showed varied mineral compositions (Table 2). Jumbo dates contained the highest levels of calcium (38.56 mg/100 g), magnesium (122.71 mg/100 g), and iron (6.96 mg/100 g). Small dates exhibited the highest potassium (553.12 mg/100 g) and sodium (37.39 mg/100 g) content. LRFDSP contained substantial mineral concentrations: 68.17 mg/100 g calcium, 243.37 mg/100 g potassium, 16.57 mg/100 g sodium, 56.63 mg/100 g magnesium, and 0.91 mg/100 g iron, confirming date seeds as excellent mineral sources (Ramadan et al., 2017).

3.2.3 Phytochemical Compounds

LRFDSP demonstrated exceptionally high phytochemical compound content (Table 2), carotenoids (81.94 mg/100g FW), total phenolics (1978.01 GAE mg/100g DWB), and tannins (144.43 mg/100 g FW). These results support findings by Nasir et al. (2015), who noted that dietary antioxidants, including phenolic compounds in dates, help activate both enzymatic and non-enzymatic antioxidant systems.

Table 2. Chemical Properties, Mineral Contents, and Phytochemical Compounds of Saidy Cultivar Date Flesh (on a size basis) and LRFDSP.

Property	Dates on a Size Basis			LRFDSP
	Small	Moderate	Jumbo	
Chemical Composition				
Moisture (%)	15.22^{c}	16.55^{b}	17.35^{a}	5.47^{d}
Total carbohydrates (%)	76.49^{b}	74.23^{c}	73.17^{d}	83.66^{a}
Reducing sugars (%)	72.86^{a}	70.12^{b}	69.01^{c}	ND
Non-reducing sugars (%)	3.34^{c}	3.66^{b}	3.73^{a}	ND
Crude fiber (%)	2.56^{b}	2.88^{b}	3.00^{b}	74.27^{a}
Crude protein (%)	2.27^{d}	2.37^{c}	2.41^{b}	6.67^{a}
Crude fat (%)	1.23^{d}	1.37^{c}	1.47^{b}	8.11^{a}
Ash (%)	2.18^{c}	2.33^{b}	2.45^{a}	1.55^{d}
Mineral Contents (mg/100g)				
Calcium	35.57^{c}	37.62^{b}	38.56^{b}	68.17^{a}
Potassium	553.12^{a}	550.55^{b}	546.47^{c}	243.37^{d}
Sodium	37.39^{a}	34.98^{b}	30.61^{c}	16.57^{d}
Magnesium	117.67^{c}	120.62^{b}	122.71^{a}	56.63^{d}
Iron	5.09^{b}	6.47^{a}	6.96^{a}	0.91^{c}
Phytochemical Compounds (mg/100g)				
Carotenoids (FW)	12.68^{b}	9.90^{c}	7.35^{d}	81.94^{a}
Total phenolics (GAE, DWB)	274.67^{b}	262.67^{c}	252.67^{c}	1978.01^{a}
Total tannins (FW)	0.44^{b}	0.42^{b}	0.41^{b}	144.43^{a}

Values in the same row with different superscripts are significantly different ($p < 0.05$). ND = Not detected; GAE = Gallic Acid Equivalents; FW = Fresh Weight; DWB = Dry Weight Basis

3.3 Effects of LRFDSP Fortification on Nutritional Properties of Jumbo Functional Dates

3.3.1 Physicochemical Properties

Table 3 summarizes the physicochemical properties of jumbo functional dates fortified with varying levels of LRFDSP. Unfortified pitted dates (control) exhibited the highest moisture content (17.35%), while jumbo functional dates fortified with 1.60 g LRFDSP showed the lowest (15.80%). This reduction enhances product stability by decreasing water activity.

Total sugars decreased significantly from 73.18% in control to 64.93% in the highest fortification level of jumbo functional dates, with corresponding reductions in reducing sugars (69.01% to 60.21%) and non-reducing sugars (3.70% to 3.21%). These changes reflect the dilution effect of low-sugar LRFDSP addition (Rodríguez et al., 2016).

Crude fiber content increased dramatically from 3.00% in control to 12.29% in the highest fortification level of jumbo functional dates, representing a four-fold improvement. This enhancement aligns with findings by Al-Farsi et al. (2007), who emphasized the importance of dietary fiber in preventing various diseases including cardiovascular disease, diabetes, and certain cancers.

Crude protein content increased progressively from 2.41% to 2.95%, and crude lipids from 1.47% to 2.34% with increasing fortification levels from 0.00 to 1.60 g LRFDSP, respectively. These improvements reflect the higher protein and lipid content of LRFDSP compared to date flesh (Hamada et al., 2002).

3.3.2 Mineral Contents

Fortification of jumbo dates with LRFDSP from 0.00 to 1.60 g LRFDSP as shown in Table 3 resulted in increased calcium content (38.56 to 42.42 mg/100 g) while decreasing potassium (546.47 to 508.39 mg/100 g), sodium (30.61 to

28.61 mg/100 g), magnesium (122.71 to 114.10 mg/100 g), and iron (6.96 to 6.17 mg/100 g) concentrations, respectively. These changes reflect the mineral profile differences between date flesh and seed powder (Renna et al., 2013).

3.3.3 Phytochemical compounds

Fortification with LRFDSP significantly enhanced the phytochemical profile of jumbo functional dates (Table 3). Total flavonoids increased from 4.53 mg RE/100g FW in control to 241.92 mg RE/100g FW in the highest (1.60 g) fortification level. Total phenolic compounds rose from 275.93 to 495.96 mg GAE/100g DWB, while tannins increased from 0.41 to 18.87 mg TAE/100g FW with increasing fortification from 0.00 to 1.60 g LRFDSP, respectively.

These substantial improvements in antioxidant compounds support the health-promoting potential of fortified jumbo dates. Vayalil (2012) reported that dates naturally contain 1-2% phenolic antioxidants, and our results demonstrate significant enhancement through seed powder incorporation.

Table 3. Properties of Jumbo Functional Dates Fortified with LRFDSP

Property	Control (0.00 g)	Medium (0.80 g)	High (1.60 g)
Chemical Composition			
Moisture (%)	17.35^{a}	15.90^{b}	15.80^{c}
Total sugars (%)	73.18^{a}	68.67^{b}	64.93^{c}
Crude fiber (%)	3.00^{c}	7.84^{b}	12.29^{a}
Crude protein (%)	2.41^{c}	2.71^{b}	2.95^{a}
Crude lipids (%)	1.47^{c}	1.94^{b}	2.34^{a}
Mineral Contents (mg/100g)			
Calcium	38.56^{c}	40.62^{b}	42.42^{a}
Potassium	546.47^{a}	525.53^{b}	508.39^{c}
Phytochemical Compounds (mg/100g)			
Total flavonoids (RE, FW)	4.53^{c}	131.53^{b}	241.92^{a}
Total phenolics (GAE, DWB)	275.93^{c}	394.40^{b}	495.96^{a}
Total tannins (TAE, FW)	0.41^{c}	9.80^{b}	18.87^{a}

Values in the same row with different superscripts are significantly different ($p < 0.05$)

3.3.4 Sensory Evaluation

Sensory evaluation results demonstrated that LRFDSP incorporation positively influenced the sensory attributes of jumbo functional dates (Figure 1). All fortified jumbo samples received higher scores than control across multiple attributes. Appearance scores increased from 7.67 to 8.63, flavor improved from 8.09 to 8.65, and overall acceptability rose from 7.92 to 8.35 with increasing fortification from 0.00 to 1.60 g LRFDSP, respectively.

These results suggest that moderate roasting of date seeds produces desirable flavor compounds that enhance rather than detract from the sensory experience. The findings align with Vilela et al. (2015), who concluded that functional food consumption relates to good nutritional status and contributes to preventing degenerative processes.

4. Conclusion

This study demonstrates the significant potential of date seed by-product as a valuable resource for jumbo functional dates production. Low-roasted full date seed powder (LRFDSP) represents a rich source of dietary fiber and bioactive compounds that can substantially enhance the nutritional profile of conventional date products.

Key findings include:

1. **Nutritional Enhancement:** Fortification with LRFDSP increased crude fiber content by over 300% (from 3.00% to 12.29%), while significantly boosting protein and lipid content.
2. **Antioxidant Improvement:** Total phenolic compounds increased by 80% (from 275.93 to 495.96 mg GAE/100g DWB), and flavonoid content increased dramatically from 4.53 to 241.92 mg RE/100g FW.
3. **Consumer Acceptance:** Sensory evaluation demonstrated improved acceptability with

fortification, indicating strong commercial potential.

4. **By-product Valorization:** This approach provides a sustainable solution for managing the substantial volumes of date seed waste generated annually by the industry.

The resulting jumbo functional dates represent a novel food product with enhanced health benefits, aligning with growing consumer demand for natural, fiber-rich foods. This research contributes to the development of value-added products from agricultural waste while supporting circular economy principles in food processing.

Future research should explore the long-term storage stability of these functional dates, investigate the bioavailability of incorporated bioactive compounds, and evaluate scaling potential for commercial production. The development of such value-added products from date seed waste presents promising opportunities for the food industry and supports sustainable agricultural practices.

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Abbreviations

- **DF:** Dietary fibers
- **DWB:** Dry weight basis
- **FW:** Fresh weight
- **GAE:** Gallic acid equivalents
- **LRFDSP:** Low-roasted full date seed powder
- **RE:** Rutin equivalents
- **TAE:** Tannic acid equivalents

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Figures

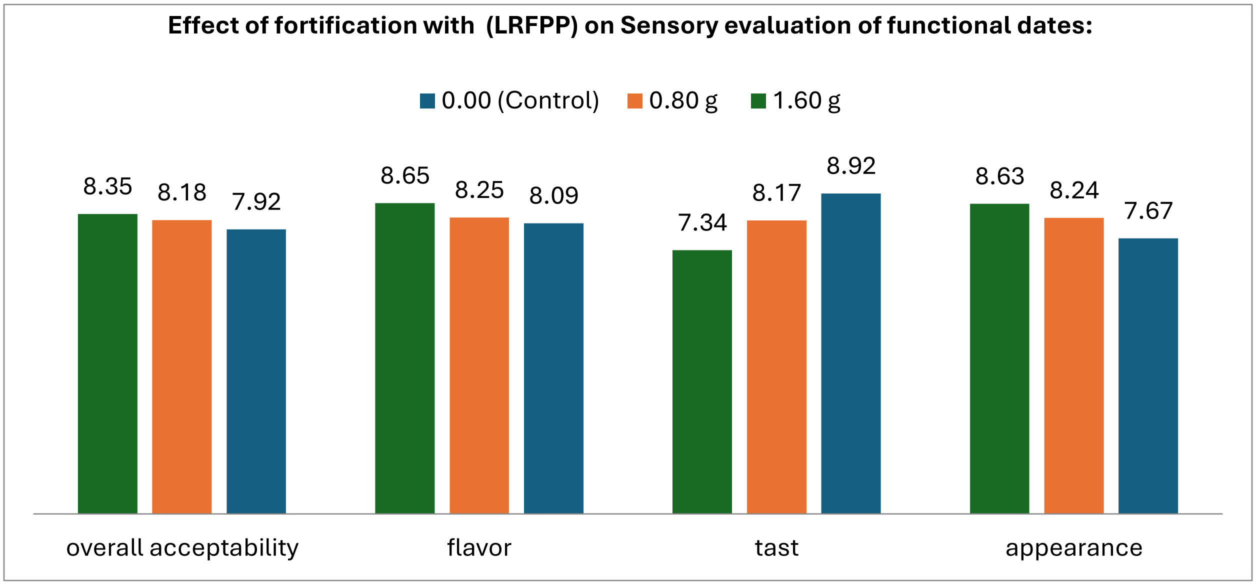

Figure 1. Sensory Evaluation of Jumbo Functional Dates Fortified with LRFDSP

A bar chart showing sensory scores (0-10 scale) for appearance, taste, flavor, and overall acceptability across three treatments: Control (0.00 g), Medium fortification (0.80 g), and High fortification (1.60 g). All fortified samples showed improved scores compared to control, with the highest fortification level achieving the best sensory ratings.

Figure 2. Methodology Flowchart for Functional Date Production

A process flow diagram illustrating: Date selection and cleaning → Seed separation and washing → Air drying at 50°C → Roasting at 120°C for 20 min → Grinding through 80 μm mesh → Fortification of pitted dates at different levels → Quality analysis and sensory evaluation.

Statistical Analysis Summary

All experiments were conducted in triplicate, and results are expressed as mean ± standard deviation. Analysis of variance (ANOVA) was performed using Microsoft Excel 2019 with statistical significance determined at $p < 0.05$. Post-hoc comparisons were conducted using Tukey's HSD test for multiple comparisons. Different superscript letters in tables indicate statistically significant differences between treatments.

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Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest. The research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

Ethical Considerations

This study involved only plant materials and food products. No human subjects or animal testing were involved beyond standard sensory evaluation procedures conducted with informed consent from trained panelists.