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Harnessing desert date seeds for sustainable and nutritious functional food formulations

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Abstract
The increasing demand for sustainable and functional food products has led to the exploration of agro-industrial by-products for nutritional enhancement. *Balanites aegyptiaca*, a wild tree native to arid regions, yields nutrient-rich seed cake as a by-product after oil extraction. This study investigates the valorization of Desert date oilseed cake into protein rich flour and its incorporation into functional food development in the form of edible cookies at varying levels (100–200 g). Incorporation of 150 g Desert date flour (C-150) yielded cookies with optimal sensory acceptability and improved functional attributes. Physical hardness and color darkening increased with higher substitution levels, while sensory scores declined beyond 150 g. The study demonstrates that Desert date flour can serve as a viable, sustainable ingredient in bakery products, aligning with circular bioeconomy and nutritional security goals.

Keywords: *Balanites aegyptiaca*, desert date, seed cake flour, oilseed by-product, high-protein flour, food fortification, bakery product, wild edible plants

Introduction

The global food system must simultaneously minimize food waste, encourage sustainability, and ensure nutritional security. Consumer demand for foods that provide functional and therapeutic benefits in addition to essential nutrients continues to rise as a consequence of a dramatic rise in lifestyle-related medical conditions like obesity, diabetes, and cardiovascular disorders [1]. In this context, using agro-industrial by-products has evolved into an appealing means of producing functional food ingredients while also advancing the objectives of a circular bioeconomy [2]

In 2020, Europe alone generated an estimated 59 million tons of food waste [3]. The Food and Agriculture Organization (FAO) notes that a large portion of food is wasted, with the amount varying by product. For example, oilseeds and pulses account for a 20% loss [4], Food waste and by-products, which are usually considered low-value, actually have great potential for creating valuable compounds [5].

Among the underutilized plant resources, *Balanites aegyptiaca* (L.) Delile, also known as Desert date, belonging to the family Zygophyllaceae, is a multipurpose tree widely distributed in arid and semi-arid regions of Africa, the Middle East, and South Asia [6].

Traditionally, various parts of this plant have been employed in folk medicine for the treatment of ailments such as jaundice, skin infections, helminthic diseases, and diabetes [7, 8] Its seeds are an important source of oil, often compared with commercial vegetable oils, while the residual oilseed cake—a major by-product of oil extraction is typically discarded or relegated to animal feed. This practice overlooks its potential as a nutritionally dense and bioactive-rich material.

In recognition of its desirable nutritional constituents, the defatted seed flour made from desert date oilseed cake is currently gaining scientific interest. According to studies, it is very high in phenolic compounds, dietary fiber, proteins, and essential amino acids [9].

The substance's ability to combat free radicals and reduce oxidative stress, which is a major factor in the etiology of chronic illnesses like cancer, Type 2 diabetes, and cardiovascular disease is improved further by the presence of natural antioxidants like flavonoids, saponins, and phenolic acids [10]. Due to its bioactive qualities, desert date flour is an appealing choice for use in healthcare preparations, nutraceuticals, and functional food formulations.

Desert date flour is also notable as rich in protein content. This quality is very useful for managing various metabolic disorder through nutrition. Furthermore, the inclusion of dietary fiber and resistant starch improves the efficiency of digestion, encourages satiety, and supports gut health [11]. Vegan, high in fiber, and enriched in protein foods are popular in today's diets because of these qualities.

From an environmental perspective, turning Desert date oilseed cake into functional flour not just offers a way to reduce waste and use resources more efficiently, but it also helps rural populations in desert areas where this tree is widely grown to improve their socioeconomic standing. This approach fills the disparity between food technology, dietary requirements, and sustainability by turning a wasteful by-product into a high-value nutritional component, supporting the circular bioeconomy and zero-waste processing concepts.

Thus, the nutritional profile and functional food uses of desert date defatted seed flour are the main topics of this study. The goal of this research is to promote desert date flour as a sustainable, value-added ingredient for the food and pharmaceutical sectors by demonstrating its nutritional richness and health-promoting qualities. This will open up new avenues for innovation in the fields of functional foods and nutraceuticals.

Materials and Methods

Material Collection and Making defatted flour

Fruits were collected from wild conditions. Seeds were separated, cleaned, and soaked in boiling water for 40 minutes. After boiling, the shelled kernels were dried at room temperature for 2 days. The resulting seed cake was then ground into a fine powder using a mixer-grinder and subsequently passed through a No. 20 mesh sieve. The defatting process of the resulting powder was conducted using a Soxhlet apparatus, with n-hexane as the solvent, for a duration of 3 hours, following the standard procedure described by AOAC [12]. After the extraction of oil, the hexane was removed from the defatted material using a rotary evaporator.

Functional Properties of Desert date Seed Flour

1. Water Absorption Capacity (WAC)

Water absorption capacity was measured using the method outlined by Beuchat [13], with slight modifications. One gram (1.0 g) of flour sample was accurately weighed into a pre-weighed 15 mL centrifuge tube. Ten millilitres (10 mL) of distilled water were added to the sample, and the mixture was vortexed for 30 seconds to achieve uniform dispersion. The sample was then allowed to stand at room temperature (25 ± 2 °C) for 30 minutes and subsequently centrifuged at 3000 × g for 20 minutes. The supernatant was carefully decanted to avoid disturbance of the sediment, and the tube containing the residual sediment was subsequently weighed with precision.

Water absorption capacity was expressed as the amount of water absorbed (in grams) per gram of flour, calculated using the following formula:

WAC (g/g) = (Weight of tube + wet sediment – weight of empty tube)/Weight of dry sample

2. Oil Absorption Capacity (OAC)

The method of Sosulski [14] has been followed to measure Oil absorption capacity with slight modifications. 1 gm of fine dried flour was mixed with 10 mL of refined soybean oil, and stirred with a vortex mixer for 30 seconds. The mixture was allowed to rest at ambient temperature for 30 minutes to facilitate phase separation, after which it was subjected to centrifugation at 3000 × g for 20 minutes. The liberated oil layer was gently decanted, and the resulting residue was accurately weighed for further analysis.

OAC (g/g) = (Weight of tube + oil retained – weight of empty tube)/Weight of dry sample

3. Bulk Density

The method of Onwuka [15] was used to calculate bulk density. A 10 mL graduated cylinder was filled with the flour sample, gently tapped 10 times to ensure uniform packing. The final volume was recorded, and the weight was accurately determined using an analytical balance. The bulk density was calculated using the formula:

Bulk density (g/mL)=weight of sample (g)/volume occupied (mL)

4. Emulsification Capacity

The method of Yasumatsu *et al*. [16] was used to measure the emulsification capacity. The flour sample (1 g) was weighed, homogenized with 10 ml distilled water, and gradually added 10 ml refined vegetable oil to create a stable oil-in-water emulsion for 1 min. The emulsion was then centrifuged at 1300 × g for 5 minutes to separate it into layers based on density. The emulsifying activity was calculated as the percentage of the emulsified layer relative to the total volume of the contents. The test was repeated for accuracy and reproducibility

Emulsification Capacity (%) = (Height of emulsified layer/Total height of mixture) × 100

5. Cookie Formulation

Cookies were prepared using Ragi and Oat flour partially substituted with Desert date flour at different proportion as mentioned in (Table 1). The recipe included flour blend, jaggery, olive oil, nuts, baking powder and baking soda. The dough was rolled, shaped, and baked at 180°C for 15 minutes. Fig 1 depicting the cookie formulation.

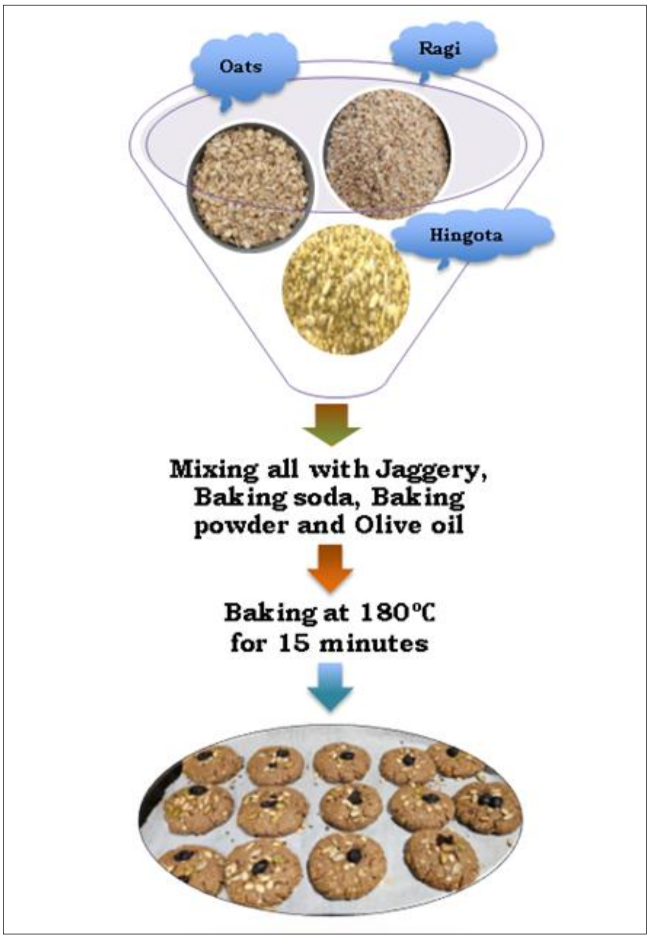

Table 1: Compositional variations in cookie formulations to assess the effect of *B. aegyptiaca* seed flour content

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Cookie	*B. aegyptiaca* flour (g)	Ragi (g)	Oats (g)	Jaggery (g)	Mixed Nuts (g)
C-100	100	250	125	125	125
C-125	125	250	125	125	125
C-150	150	250	125	125	125
C-175	175	250	125	125	125
C-200	200	250	125	125	125

5.1 Physical and Sensory Evaluation

Cookie diameter, thickness, spread ratio, and hardness were recorded. Sensory evaluation was performed by a semi-trained panel using a 9-point hedonic scale for color, texture, flavour, and overall acceptability.

6. Statistical analysis

Results and Discussion

This study shows that the by-product of oil extraction, defatted seed cake flour of Desert date can be used as a nutritious and useful ingredient in cookies and other bakery products.

1. Functional Properties

Desert date flour exhibited good water (2.4 g/g) and oil absorption capacity (1.8 g/g), beneficial for moisture retention and mouthfeel in baked products. Bulk density was 0.62 g/mL, indicating good packaging and handling properties. The water and oil absorption capacities of Desert date flour play a significant role in enhancing dough hydration and fat retention, which are critical for improving the texture and shelf-life stability of cookies [17]. These functional traits have been observed in other plant-based protein flours, such as defatted groundnut and moringa seed flours [18], reinforcing the viability of Desert date flour in baked goods.

2. Cookie Quality Attributes

2.1 Physical and Textural Properties

The incorporation of *B. aegyptiaca* seed flour in varying proportions (100 g to 200 g) significantly influenced the physical and textural attributes of cookies (Table 2). As the proportion of Desert date flour increased, notable changes were observed in spread ratio, hardness, and surface color.

The spread ratio decreased slightly from 6.11 in C-100 (100 g flour) to 5.84 in C-200 (200 g), indicating reduced dough expansion during baking. This reduction can be attributed to the higher fiber and protein content of Desert date flour, which increases water absorption and dough viscosity, thereby restricting dough flow and spread. Similar trends were observed in cookies made with *Moringa* seed flour, where higher fiber content reduced cookie expansion [19].

Hardness, as determined by a texture analyzer, progressively increased from 24.32 N in C-100 to 31.45 N in C-200, highlighting a significant impact of Desert date flour on cookie firmness. The denser structure created by fiber and protein likely contributed to reduced porosity and increased rigidity of the cookie matrix. This is consistent with another finding that observed increased hardness in cookies fortified with plantain and mushroom flour due to higher fiber density and lower moisture content [20].

Color attributes also changed significantly. Lightness (L* value) decreased from 61.23 in C-100 to 55.18 in C-200, while both a* (redness) and b* (yellowness) values increased with higher Desert date flour levels. These changes are indicative of intensified Maillard reactions and caramelization during baking, attributed to higher sugar and protein content. The natural pigments present in Desert date flour may also contribute to this darker coloration. Similarly, darkening reported in jackfruit-seed-fortified cookies due to increased non-enzymatic browning [21].

Table 2: Physical and textural attributes of Desert date flour cookies. Values represent mean ± standard deviation (n = 3). Means in the same column with different superscript letters (a–e) differ significantly at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT).

Sample	Spread ratio	Hardness (Texture analyzer)	Colour		
			Lightness	Redness	Yellowness
C-100	6.11 ± 0.21^a	24.32 ± 1.12^e	61.23 ± 1.21^a	7.32 ± 0.41^e	19.45 ± 1.10^e
C-125	6.05 ± 0.19^a	26.78 ± 1.18^d	59.88 ± 1.14^b	7.89 ± 0.39^d	20.26 ± 1.08^d
C-150	5.97 ± 0.18^b	28.54 ± 1.24^c	58.31 ± 1.09^c	8.35 ± 0.42^c	21.14 ± 1.11^c
C-175	5.89 ± 0.17^c	30.17 ± 1.31^b	56.75 ± 1.07^d	8.76 ± 0.43^b	21.94 ± 1.07^b
C-200	5.84 ± 0.18^c	31.45 ± 1.34^a	55.18 ± 1.09^e	9.14 ± 0.39^a	22.64 ± 1.08^a

2.2 Sensory Evaluation

Sensory attributes of the cookies were evaluated for appearance, texture, flavour, and overall acceptability using a 9-point hedonic scale (Table 3). Cookies with 150 g Desert date flour (C-150) achieved the highest overall acceptability (8.3), indicating a favorable balance between taste, texture, and visual appeal.

The nutty flavour and slight crispness conferred by the Desert date flour were positively perceived up to C-150. Beyond this level (C-175 and C-200), a noticeable decline was observed in all sensory parameters. For instance, in C-200, texture and flavor scores dropped to 6.8 and 6.4, respectively, suggesting excessive hardness and a mildly bitter aftertaste. The darker appearance and reduced mouthfeel might also have influenced sensory rejection at higher levels.

This pattern aligns with other studies on functional flours. A study reported that flaxseed flour enhanced sensory properties only up to 18% inclusion [22]. It is also noted that moderate substitution levels of baobab flour in cookies yielded the highest acceptability, with further increases leading to undesirable texture and flavour [23].

Table 3: Sensory evaluation scores of cookies prepared with varying levels of Desert date flour. Values are expressed as mean ± standard deviation (n = 30) based on a 9-point hedonic scale. Means in the same column with different superscript letters (a–d) are significantly different at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT).

Sample	Appearance	Texture	Flavour	Overall Acceptability
C-100	7.8 ± 0.3^b	7.5 ± 0.4^b	7.2 ± 0.5^c	7.6 ± 0.4^b
C-125	8.1 ± 0.3^a	7.9 ± 0.3^a	7.7 ± 0.4^b	8.0 ± 0.3^a
C-150	8.2 ± 0.4^a	8.1 ± 0.3^a	8.0 ± 0.4^a	8.3 ± 0.3^a
C-175	7.4 ± 0.4^c	7.2 ± 0.5^c	7.1 ± 0.5^c	7.3 ± 0.4^c
C-200	7.0 ± 0.5^d	6.8 ± 0.5^d	6.4 ± 0.6^d	6.9 ± 0.5^c

3. Optimal Formulation Insight

Among the tested formulations, C-150 was the most acceptable under the present experimental conditions, as evaluated by a semi-trained panel. At this level, the cookies exhibit improved nutritional properties without compromising texture or palatability. Beyond this threshold, increased density and bitterness diminish consumer appeal. Future studies involving consumer panels will further validate product acceptability."

Implications for Sustainability

The valorization of Desert date seed flour represents a sustainable approach to waste utilization from oil extraction processes. Typically discarded or used as animal feed, Desert date seed cake flour is now shown to be a promising ingredient for functional foods [24, 25]. Its inclusion promotes circular bioeconomy practices and aligns with FAO's [4] advocacy for biodiversity-based nutrition strategies. In regions prone to drought or food insecurity, such as arid parts of India and Africa where *B. aegyptiaca* naturally grows, this approach offers both nutritional and ecological benefits [26, 27, 28]. Recent studies have further highlighted the potential of *B. aegyptiaca* seed flour in the development of antioxidant-rich and nutritionally fortified food products, supporting its role in climate-resilient, health-oriented food systems [29, 30, 31].

Conclusion

This study highlights the potential of *B. aegyptiaca* seed cake flour, a by-product of oil extraction, as a valuable functional ingredient in bakery formulations. Rich in protein, dietary fiber, and antioxidants, Desert date flour enhanced the nutritional and functional profile of cookies, particularly at a 150 g inclusion level, where sensory acceptability remained high. Above this level, increased hardness and flavor bitterness impacted consumer appeal. The valorization of Desert date seed cake not only contributes to waste reduction but also supports the development of health-promoting and diabetic-friendly food products. The findings support the integration of wild and underutilized crops into mainstream food systems, thereby addressing both nutritional and environmental sustainability. Conflicts of interest: The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report.

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