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Nutritional and Anti-Nutritional Responses of Date Nuts (*Phoenix dactylifera* L.) to Graded Boiling Durations: Implications for Animal Feed Utilisation

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Abstract

This study investigated the effect of boiling duration on the nutritional and anti-nutritional composition of date palm (Phoenix dactylifera L.) seeds to identify an optimal processing time for feed application. Seeds were subjected to boiling for 0 (control), 30, 60, 90, and 120 min, and analysed for vitamins, minerals, proximate, fibre fraction, and anti-nutrient composition using standard procedures. All parameters were significantly ($p < 0.05$) affected by boiling duration, except tannins, magnesium, protein, fibre, and ash. Vitamin A and thiamine peaked at 30 min (212.17 µg/100 g and 6.66 mg/100 g, respectively) before declining, while folate was highest in the control (759.98 µg/100 g) and reduced in all boiled treatments. Haemagglutinin decreased from 5.39 HU/g in control to 3.54 HU/g at 60 min, and oxalate was significantly reduced at 60 min (6.55 mg vs 7.73 mg in the control). Phytate and saponin exhibited non-linear responses, with peaks at 60 min. Crude fat declined from 4.61% in the control to approximately 2.1–2.3% in boiled samples, while protein (22.39–23.90%), fibre (21.14–22.91%), and ash (3.22–3.42%) remained stable. Lignin decreased significantly at 60 min (0.98% vs 2.22% in the control), indicating partial solubilization of lignocellulosic bonds. Boiling for 30 to 60 min is recommended as offering a favourable balance between nutrient retention, anti-nutrient reduction, and improved fibre digestibility potential for date seed incorporation into animal diets.

Keywords: Date nuts; boiling; anti-nutrients; proximate composition; feed processing

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Introduction

Date palm (*Phoenix dactylifera* L.) is an important fruit crop, and its processing generates date seeds as a major by-product. Date seeds are recognized as a potentially useful material because they contain vitamins, minerals, fibre, and other bioactive components, and their composition is known to be influenced by variety and by processing (Alhuzali *et al.*, 2019; Al-Jaloud *et al*., 2020). Fresh dates have been reported to contain higher vitamin concentrations than dried dates, with vitamins depleted during prolonged drying and boiling as a result of leaching (Alhuzali *et al*., 2019; Hamad *et al*., 2015). Date seeds have also been reported to contain high levels of phenolics, approximately 3942 mg/100 g, with a large proportion present as bound tannins in the seed coat (Al-Farsi *et al*., 2005). These characteristics make date seeds a candidate feed and food ingredient but also mean that their nutritional value is strongly dependent on how they are processed.

The presence of anti-nutritional factors is a major constraint to the direct use of date seeds. Plant foods in general contain anti-nutritional factors such as phytate, oxalate, saponin, tannin, haemagglutinin, and protease inhibitors, which can reduce nutrient bioavailability, and processing strategies are required to reduce them (Samtiya *et al*., 2020; Samtiya *et al*., 2021). Boiling is one of the most widely used and practical hydrothermal treatments for this purpose. Boiling has been reported to substantially improve the nutritional value of plant foods by reducing lectins and haemagglutinins (Maphosa & Jideani, 2017; Samtiya *et al*., 2020). Hydrothermal processing of *Mallotus subulatus* caused significant decreases in phytic acid, saponin, and tannin, and eliminated trypsin inhibitor activity under pressure boiling (Adeyemi *et al*., 2021). In *Sphenostylis stenocarpa*, boiling reduced oxalate, phytate, and tannin (Abu *et al*., 2020). However, the response of individual anti-nutrients to boiling is not uniform. Soaking and short cooking drastically decreased phytate, but prolonged cooking can increase its apparent concentration through dry matter loss and the formation of insoluble phytate–protein–mineral complexes (Ertaş & Türker, 2014, as cited in Samtiya *et al*., 2021; Vadivel & Biesalski, 2012, as cited in Samtiya *et al*., 2021). Similarly, some processing methods have been reported to increase measurable saponin, because hydration allows water to penetrate the seed interior and release more saponins by simple diffusion (Adeyemi, 2020; Odufuwa *et al*., 2007). Date seeds gain approximately 25% weight after 72 h of soaking (Zaid, 2002, as cited in Al-Farsi, 2020), which supports the view that hydration-driven changes can alter the extractability of seed components during boiling. These contrasting effects mean that the duration of boiling is likely to be a critical determinant of the final nutritional quality of date seeds, yet systematic data on graded boiling durations for date seeds are limited.

Thermal processing also has important effects on vitamins and minerals. Brief hot water treatment of dates improved drying efficiency while maintaining phytochemicals and reducing tannins from 2.52% in the control to 1.43% at 10 min, indicating that short hydrothermal treatment can disrupt the hard seed matrix and release bound vitamins (Li *et al*., 2023). In Djansang seeds (*Ricinodendron heudelotii*), vitamin A increased with boiling duration (10.08–11.23 mg/100 g) while vitamin E declined, and 2 h at 80 °C was identified as optimal for vitamin retention (Nwuzoh *et al*., 2024). Blanching of kale and spinach showed that vitamin C is the most sensitive vitamin to heat and leaching, with a loss of 3.60 mg/100 g per minute increase in blanching time, and trends in vitamin C loss were similar to potassium loss (Yuan *et al.*, 2022). Niacin is more heat stable than thiamine and riboflavin, which are significantly reduced by prolonged boiling, partly through Maillard reactions that reduce lysine availability (Alrosan *et al*., 2025; Samtiya *et al.*, 2020). Boiling has also been reported to decrease potassium, phosphorus, magnesium, zinc, manganese, and iron in plant tissues through leaching (Al-Jaloud *et al*., 2020; Bethke & Jansky, 2008; Ismail *et al*., 2020). At the same time, heat treatment can increase measurable mineral content through matrix softening and improved extractability, and reduction in phytate can lower mineral chelation and enhance free mineral contents (Hamza & Al-Hashimi, 2023; Samtiya *et al*., 2021). Crude fat has been reported to decrease significantly with boiling (34.08–39.28 mg/100 g) owing to lipid leaching (Nwuzoh *et al*., 2024), while crude protein in winged bean was 17.93% when baked and 19.59% when boiled, compared with 12.55% in the control, indicating that protein is heat stable at 100 °C for short processing times (Ogundana *et al*., 2020). Steam treatment of date leaves significantly affected cell wall components, decreasing NDF but increasing ADL, with maximum changes in hemicellulose (Adeyemi, 2021; Karimi *et al.*, 2012). Date seeds were traditionally soaked before feeding to ruminants (Al-Okbi, 2022; Zaid, 2002), which further supports the practical relevance of evaluating hydrothermal processing for this by-product.

Taken together, the available evidence indicates that boiling duration can either improve or impair the nutritional quality of date seeds depending on the parameter considered, and that the balance between nutrient retention and anti-nutrient reduction is likely to be duration-dependent. The present study was therefore designed to evaluate the effect of graded boiling durations (0, 30, 60, 90, and 120 min) on the vitamin, mineral, proximate, fibre fraction, and anti-nutrient composition of date palm seeds, with the objective of identifying a boiling duration that offers a favourable balance between nutrient retention and anti-nutrient reduction for potential use in animal feed.

Materials and methods

Description of Study Area

The experiment was carried out at the Livestock Demonstration Farm, Faculty of Agriculture, Nasarawa State University, Keffi, Shabu-Lafia Campus, Nasarawa State, Nigeria. Lafia is located in the Southern Guinea Savannah agro-ecological zone of Nigeria. It lies on latitude 08° 29' 48" N and longitude 08° 30' 58" E (NIMET, 2022). The area has an average annual rainfall of 1,100 - 1,600 mm and mean monthly temperature of 25 - 38°C with relative humidity of 40-75% (Ishaya and Abaje, 2008).

Collection and Identification of Date Seeds

Matured date fruits (Phoenix dactylifera L) were purchased from Lafia Modern Market, Lafia, Nasarawa State. The fruits were authenticated at the Department of Plant Science and Biotechnology, Nasarawa State University, Keffi. The date pulps were manually removed to obtain the seeds (nuts). The seeds were thoroughly washed with clean tap water to remove adhering pulp, dirt and foreign materials and were sun-dried for 72 hours to reduce moisture content and ease handling (Ameen *et al*., 2019).

Experimental Design

The experiment was laid out in a Completely Randomized Design (CRD) with five (5) treatments and three (3) replicates per

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treatment. The treatments were based on boiling duration as follows:

T1 = 0 minutes (Control) - Raw date seed

T2 = Boiled for 30 minutes

T3 = Boiled for 60 minutes

T4 = Boiled for 90 minutes

T5 = Boiled for 120 minutes

Processing of Date Seeds - Boiling Treatment

A total of 15 kg of cleaned date seeds were divided into 5 equal portions of 3 kg each (1 kg per replicate). Each portion was weighed using an electronic digital weighing scale.

The seeds were boiled in aluminum pots using tap water at a ratio of 1:3 (w/v) (seed: water) at 100°C on a gas cooker at the Livestock Farm kitchen (Kana *et al*., 2017). Boiling durations were strictly monitored with a stopwatch according to treatments T2 - T5, while T1 was not boiled.

After boiling, the water was drained off using a plastic sieve and the seeds were allowed to cool at room temperature for 2 hours. All samples including the control were then oven-dried at 60°C for 48 hours to a constant weight to prevent mould growth (AOAC, 2005).

The dried seeds were milled separately into fine powder (Date Seed Meal - DSM) using a laboratory hammer mill fitted with 2 mm sieve, packed in air-tight polythene bags, properly labelled according to treatments and replicates, and stored at room temperature for chemical analysis.

Chemical Analysis

All chemical analyses were carried out in triplicates at the Biochemistry Laboratory, Faculty of Agriculture, Nasarawa State University, Keffi

Proximate Composition

Proximate composition of date seed samples was determined according to the standard methods of the Association of Official Analytical Chemists (AOAC, 2005; 2012).

Moisture content: Determined by oven drying at 105°C to constant weight (AOAC, 2005).

Crude Protein (CP): Determined by the Kjeldahl method, where nitrogen content was multiplied by 6.25 (AOAC, 2005).

Ether Extract (EE): Determined by Soxhlet extraction method using petroleum ether (AOAC, 2005).

Crude Fibre (CF): Determined by acid-alkaline digestion method (AOAC, 2005).

Ash: Determined by incineration in a muffle furnace at 550°C for 6 hours (AOAC, 2005).

Nitrogen Free Extract (NFE): Calculated by difference using the formula:

NFE (%) = 100 - (Moisture + CP + CF + EE + Ash) (McDonald *et al*., 2011).

Mineral Composition

Minerals such as Calcium (Ca), Phosphorus (P), Potassium (K), Magnesium (Mg), Iron (Fe) and Zinc (Zn) were determined using Atomic Absorption Spectrophotometer (AAS) (Model: Buck Scientific 210 VGP) after wet digestion as described by AOAC (2005).

Anti-Nutritional Factors Determination

Tannin: Determined by Folin-Denis spectrophotometric method as described by Makkar and Goodchild (1996).

Phytate: Determined by the method of Wheeler and Ferrel (1971) and Haug and Lantzsch (1983).

Oxalate: Determined by titration method as described by Day and Underwood (1986).

Saponin: Determined by gravimetric method of Brunner (1984).

Hydrogen Cyanide (HCN): Determined by alkaline titration method (AOAC, 2005).

Trypsin Inhibitor Activity (TIA): Determined by the method of Kakade *et al*. (1974).

Data Analysis

All data obtained from the chemical analyses were subjected to one-way Analysis of Variance (ANOVA) using Statistical Package for Social Sciences (SPSS version 25.0). Significant differences between treatment means were separated using Duncan's Multiple Range Test (DMRT) as outlined by Duncan (1955) at 5% level of significance ($p<0.05$).

Results

Vitamin Composition (Table 1)

All vitamin parameters were significantly ($p < 0.05$) affected by boiling duration (ANOVA df = 4,10). Vitamin A (RE) was higher in seeds boiled for 30 mins (212.17 ± 5.49 µg/100g) than control (185.64 ± 12.23 µg/100g), while the lowest value was observed at 90 mins (150.26 ± 3.92 µg/100g). Thiamine (B1) followed a similar trend, with 30 mins (6.66 ± 0.07 mg/100g) significantly higher than all other treatments, while 90 and 120 mins had the lowest values (4.04 ± 0.17 and 3.90 ± 0.05 mg/100g respectively). Riboflavin (B2) was highest in the control (3.00 ± 0.15 mg/100g) and was significantly reduced by boiling for 60 mins (2.03 ± 0.07 mg/100g) and 90 mins (2.00 ± 0.09 mg/100g). Niacin content increased with boiling duration, with 120 mins (2.62 ± 0.07 mg/100g) being significantly higher than control (1.92 ± 0.09 mg/100g) and 30 mins (1.52 ± 0.01 mg/100g) which had the lowest value. Folate (B9) was significantly highest in the control (759.98 ± 35.50 µg/100g) and significantly reduced in all boiled treatments (654.95 - 689.90 µg/100g). Vitamin C was significantly highest at 60 mins (10.61 ± 0.49 mg/100g), while 30 mins (7.00 ± 0.14 mg/100g) and 90 mins (7.21 ± 0.16 mg/100g) were significantly lower than control (8.59 ± 0.31 mg/100g).

Table 1. Mean vitamin composition of date nuts as affected by boiling duration

Boiling Duration	Vitamin A (RE) (µg/100g)	Thiamine (B1) (mg/100g)	Riboflavin (B2) (mg/100g)	Niacin (mg/100g)	Folate (B9) (µg/100g)	Vitamin C (mg/100g)

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Boiling Duration	Vitamin A (RE) (µg/100g)	Thiamine (B1) (mg/100g)	Riboflavin (B2) (mg/100g)	Niacin (mg/100g)	Folate (B9) (µg/100g)	Vitamin C (mg/100g)
Control	185.64 ± 12.23^{b}	4.78 ± 0.11^{b}	3.00 ± 0.15^{a}	1.92 ± 0.09^{c}	759.98 ± 35.50^{a}	8.59 ± 0.31^{b}
30mins	212.17 ± 5.49^{a}	6.66 ± 0.07^{a}	2.65 ± 0.25^{b}	1.52 ± 0.01^{d}	654.95 ± 28.07^{b}	7.00 ± 0.14^{c}
60mins	173.38 ± 0.45^{b}	4.73 ± 0.29^{b}	2.03 ± 0.07^{c}	2.16 ± 0.05^{b}	661.66 ± 11.30^{b}	10.61 ± 0.49^{a}
90mins	150.26 ± 3.92^{c}	4.04 ± 0.17^{c}	2.00 ± 0.09^{c}	2.25 ± 0.04^{b}	689.90 ± 17.60^{b}	7.21 ± 0.16^{c}
120mins	179.86 ± 8.66^{b}	3.90 ± 0.05^{c}	2.89 ± 0.02^{ab}	2.62 ± 0.07^{a}	676.39 ± 35.47^{b}	9.08 ± 0.42^{b}

ANOVA df = 4, 10; all properties significant at $p < 0.05$. Means bearing different superscript letters within the same column differ significantly ($p < 0.05$); means bearing the same superscript letter within the same column do not differ significantly ($p > 0.05$). Values are Mean ± SD of three replicates (n = 3). Superscripts are read down each column only, and are not comparable across rows or between columns.

Anti-nutrient (Phytochemical) Composition (Table 2)

All anti-nutrients were significantly ($p < 0.05$) affected except Tannins ($p = 0.292$). Haemagglutinin was significantly highest in control (5.39 ± 0.09 HU/g) and was reduced by boiling, with the lowest value at 60 mins (3.54 ± 0.14 HU/g). Saponin increased with boiling up to 60 mins (11.43 ± 0.09 mg), which was significantly higher than control (9.17 ± 0.30 mg) and 90 mins (9.11 ± 0.39 mg).Phytate was significantly highest at 60 mins (0.645 ± 0.016 mg) compared to control (0.449 ± 0.017 mg), while 30 mins had the lowest value (0.389 ± 0.021 mg).Oxalate was significantly reduced at 60 mins (6.55 ± 0.27 mg) compared to control (7.73 ± 0.24 mg) and other treatments. Trypsin Inhibitor Activity increased significantly with boiling duration, with 120 mins (0.092 ± 0.006 TIU/mg) significantly higher than control (0.046 ± 0.001 TIU/mg) and all other treatments. Tannins were not significantly affected, ranging from 13.85 to 14.56 mg.

Table 2. Mean antinutrient (phytochemical) composition of date nuts as affected by boiling duration

Boiling Duration	Haemagglutinin (HU/g)	Saponin (mg)	Phytate (mg)	Oxalate (mg)	Tannins (mg)	Trypsin Inhibitor Activity (TIU/mg)
Control	5.39 ± 0.09^{a}	9.17 ± 0.30^{c}	0.449 ± 0.017^{b}	7.73 ± 0.24^{a}	14.56 ± 0.11^{a}	0.046 ± 0.001^{c}
30mins	4.79 ± 0.20^{b}	9.60 ± 0.48^{bc}	0.389 ± 0.021^{d}	7.70 ± 0.58^{a}	14.37 ± 0.34^{a}	0.058 ± 0.002^{b}
60mins	3.54 ± 0.14^{d}	11.43 ± 0.09^{a}	0.645 ± 0.016^{a}	6.55 ± 0.27^{b}	14.53 ± 0.41^{a}	0.059 ± 0.002^{b}
90mins	4.51 ± 0.01^{c}	9.11 ± 0.39^{c}	0.403 ± 0.004^{cd}	7.60 ± 0.17^{a}	13.85 ± 0.79^{a}	0.064 ± 0.003^{b}
120mins	4.96 ± 0.04^{b}	10.14 ± 0.79^{b}	0.429 ± 0.022^{bc}	7.54 ± 0.22^{a}	14.13 ± 0.10^{a}	0.092 ± 0.006^{a}

ANOVA df = 4, 10; all properties significant at $p < 0.05$ except Tannins ($p = 0.292$). Means bearing different superscript letters within the same column differ significantly ($p < 0.05$); means bearing the same superscript letter within the same column do not differ significantly ($p > 0.05$). Values are Mean ± SD of three replicates (n = 3). Superscripts are read down each column only, and are not comparable across rows or between columns.

Mineral Composition (Table 3)

All minerals were significantly ($p < 0.05$) affected except Magnesium (Mg) ($p = 0.226$).Sodium was significantly highest at 60 mins (18.51 ± 0.89 mg) and lowest at 90 mins (12.74 ± 0.53 mg). Manganese was highest in control (17.52 ± 0.39 mg) and decreased significantly with boiling up to 90 mins (10.43 ± 0.17 mg).Potassium increased significantly from control (688.91 ± 32.12 mg) to peak at 90 mins (914.89 ± 12.98 mg). Copper was significantly highest at 120 mins (3.13 ± 0.19 mg) and lowest at 60 mins (1.58 ± 0.08 mg).Phosphorus was significantly reduced at 60 mins (599.45 ± 22.79 mg) compared to control (764.76 ± 23.67 mg), while 30 mins (828.61 ± 19.48 mg) and 90 mins (829.00 ± 39.16 mg) had the highest values. Zinc was highest at 60 mins (8.22 ± 0.57 mg) and lowest at 30 mins (4.70 ± 0.11 mg) and 120 mins (5.09 ± 0.26 mg).Magnesium, Iron were not significantly altered by boiling duration, indicating relative heat stability.

Table 3. Mean mineral composition of date nuts as affected by boiling duration

Boiling Duration	Sodium (Na) (mg)	Manganese (Mn) (mg)	Magnesium (Mg) (mg)	Potassium (K) (mg)	Copper (Cu) (mg)	Iron (Fe) (mg)	Phosphorus (P) (mg)	Zinc (Zn) (mg)
Control	14.38 ± 0.55^{b}	17.52 ± 0.39^{a}	24.60 ± 0.97^{a}	688.91± 32.12^{c}	1.84 ± 0.04^{c}	5.48±0.55^{ab}	764.76 ± 23.67^{a}	7.46 ± 0.29^{b}
30mins	14.53 ± 0.72^{b}	13.47 ± 0.26^{c}	27.07 ± 2.30^{a}	794.30± 32.93^{b}	2.02 ± 0.08^{c}	6.11± 0.14^{a}	828.61 ± 19.48^{a}	4.70 ± 0.11^{d}

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Boiling Duration	Sodium (Na) (mg)	Manganese (Mn) (mg)	Magnesium (Mg) (mg)	Potassium (K) (mg)	Copper (Cu) (mg)	Iron (Fe) (mg)	Phosphorus (P) (mg)	Zinc (Zn) (mg)
60mins	18.51 ± 0.89^{a}	11.30 ± 0.53^{d}	25.75 ± 0.79^{a}	797.03± 31.77^{b}	1.58 ± 0.08^{d}	5.56±0.36^{ab}	599.45 ± 22.79^{c}	8.22 ± 0.57^{a}
90mins	12.74 ± 0.53^{c}	10.43 ± 0.17^{d}	24.45 ± 0.72^{a}	914.89± 12.98^{a}	2.45 ± 0.13^{b}	5.11± 0.03^{b}	829.00 ± 39.16^{a}	6.81 ± 0.34^{c}
120mins	14.05 ± 0.53^{b}	14.64 ± 0.79^{b}	25.49 ± 1.56^{a}	725.00± 19.04^{c}	3.13 ± 0.19^{a}	6.07± 0.30^{a}	693.13 ± 57.41^{b}	5.09 ± 0.26^{d}

ANOVA df = 4, 10; all properties significant at $p < 0.05$ except Magnesium (Mg) ($p = 0.226$). Means bearing different superscript letters within the same column differ significantly ($p < 0.05$); means bearing the same superscript letter within the same column do not differ significantly ($p > 0.05$). Values are Mean ± SD of three replicates (n = 3). Superscripts are read down each column only, and are not comparable across rows or between columns.

Proximate Composition (Table 4)

Moisture, Fat, CHO and Energy were significantly affected ($p < 0.05$), while Protein ($p = 0.302$), Fibre ($p = 0.101$) and Ash ($p = 0.353$) were not significantly affected. Fat was significantly highest in control (4.61 ± 0.24%) and significantly reduced by 30 mins (2.28 ± 0.09%), 90 mins (2.06 ± 0.13%) and 120 mins (2.22 ± 0.14%).Moisture was highest at 90 mins (11.12 ± 0.38%) and lowest at 60 mins (10.00 ± 0.32%). Carbohydrate (CHO) was significantly lowest at 90 mins (34.52 ± 1.36%) compared to other treatments (36.57 - 38.63%).Energy was significantly highest in control (280.15 ± 8.61 kJ) and 60 mins (280.60 ± 2.22 kJ), and lowest at 30 mins (253.32 ± 10.66 kJ) and 90 mins (249.63 ± 16.91 kJ). Protein (22.39 - 23.90%), Fibre (21.14 - 22.91%) and Ash (3.22 - 3.42%) were stable across boiling durations.

Table 4. Mean composition of proximate composition of date seed as affected by boiling duration

Boiling Duration	Moisture (%)	Fat (%)	Protein (%)	Fibre (%)	Ash (%)	CHO (%)	Energy (kJ)
Control	10.47 ± 0.35^{abc}	4.61 ± 0.24^{a}	23.54 ± 0.57^{a}	21.14± 0.15^{a}	3.28 ± 0.18^{a}	36.57 ± 0.81^{ab}	280.15 ± 8.61^{a}
30mins	10.27 ± 0.59^{bc}	2.28 ± 0.09^{c}	23.37 ± 0.77^{a}	21.43± 0.30^{a}	3.42 ± 0.07^{a}	36.98 ± 1.26^{a}	253.32 ± 10.66^{b}
60mins	10.00 ± 0.32^{c}	4.10 ± 0.15^{b}	22.64 ± 0.95^{a}	21.43 ± 0.60^{a}	3.22 ± 0.07^{a}	37.74 ± 1.00^{a}	280.60 ± 2.22^{a}
90mins	11.12 ± 0.38^{a}	2.06 ± 0.13^{c}	23.90 ± 0.25^{a}	22.91 ± 1.00^{a}	3.32 ± 0.20^{a}	34.52 ± 1.36^{b}	249.63 ± 16.91^{b}
120mins	10.91 ± 0.22^{ab}	2.22 ± 0.14^{c}	22.39 ± 1.56^{a}	21.32 ± 1.22^{a}	3.23 ± 0.04^{a}	38.63 ± 1.30^{a}	261.10 ± 11.10^{ab}

ANOVA df = 4, 10; all properties significant at $p < 0.05$ except Protein ($p = 0.302$), Fibre ($p = 0.101$), Ash ($p = 0.353$). Means bearing different superscript letters within the same column differ significantly ($p < 0.05$); means bearing the same superscript letter within the same column do not differ significantly ($p > 0.05$). Values are Mean ± SD of three replicates (n = 3). Superscripts are read down each column only, and are not comparable across rows or between columns.

Fibre Fraction Composition (Table 5)

All fibre fractions were significantly ($p < 0.05$) affected. Neutral Detergent Fibre (NDF) was significantly higher at 90 mins (89.44 ± 4.02%) and lower at 60 mins (69.34 ± 3.03%) compared to control (74.37 ± 4.62%). Acid Detergent Fibre (ADF) was significantly higher at 120 mins (56.80 ± 2.35%) compared to other treatments (46.59 - 49.73%). Acid Detergent Lignin (ADL) and Lignin decreased significantly up to 60 mins (ADL 7.45 ± 0.37%; Lignin 0.98 ± 0.02%) from control (ADL 9.77 ± 0.34%; Lignin 2.22 ± 0.09%).Hemicellulose was significantly highest at 90 mins (40.74 ± 0.40%) and lowest at 120 mins (20.25 ± 0.44%). Cellulose was highest at 120 mins (46.19 ± 1.23%) and lowest at 90 mins (38.65 ± 1.32%).

Table 5. Mean composition of fibre fraction composition (g/kg dm) of date seed as affected by boiling duration

Boiling Duration	Neutral Detergent Fibre (NDF) (%)	Acid Detergent Fibre (ADF) (%)	Acid Detergent Lignin (ADL) (%)	Hemicellulose (%)	Cellulose (%)	Lignin (%)
Control	74.37 ± 4.62^{bc}	49.73 ± 0.45^{b}	9.77 ± 0.34^{a}	21.26 ± 0.24^{c}	43.75 ± 2.90^{ab}	2.22 ± 0.09^{a}
30mins	80.10 ± 4.55^{b}	47.70 ± 1.06^{b}	10.06 ± 0.52^{a}	31.04 ± 0.52^{b}	40.42 ± 1.32^{cd}	1.84 ± 0.02^{b}
60mins	69.34 ± 3.03^{c}	48.88 ± 2.02^{b}	7.45 ± 0.37^{c}	21.48 ± 0.42^{c}	42.21 ± 0.58^{bc}	0.98 ± 0.02^{d}

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Boiling Duration	Neutral Detergent Fibre (NDF) (%)	Acid Detergent Fibre (ADF) (%)	Acid Detergent Lignin (ADL) (%)	Hemicellulose (%)	Cellulose (%)	Lignin (%)
90mins	89.44 ± 4.02[a]	46.59 ± 1.59[b]	8.08 ± 0.20[b]	40.74 ± 0.40[a]	38.65 ± 1.32[d]	1.86 ± 0.09[b]
120mins	77.65 ± 2.40[b]	56.80 ± 2.35[a]	9.94 ± 0.15[a]	20.25 ± 0.44[d]	46.19 ± 1.23[a]	1.64 ± 0.10[c]

ANOVA df = 4, 10; all properties significant at $p < 0.05$. Means bearing different superscript letters within the same column differ significantly ($p < 0.05$); means bearing the same superscript letter within the same column do not differ significantly ($p > 0.05$). Values are Mean ± SD of three replicates (n = 3). Superscripts are read down each colum only, and are not comparable across rows or between columns.

Discussion

Vitamin Composition

The significant increase in vitamin A and thiamine (B1) at 30 min, followed by a decline at 90 min, is consistent with a short-term thermal activation effect reported for date fruit and other plant matrices. Li *et al*. (2023) demonstrated that brief hot water treatment of date fruit maintained phytochemical quality while improving drying efficiency, suggesting that short hydrothermal exposure can disrupt the seed matrix and enhance the release of bound vitamins. A comparable trend was observed by Nwuzoh *et al*. (2024) in Djansang seeds (*Ricinodendron heudelotii*), where boiling increased vitamin A content up to an optimal duration before subsequent decline, with the authors identifying 2 h at 80 °C as optimal for vitamin retention — analogous to the 30-min optimum observed here for date seed. Alhuzali *et al*. (2019) and Hamad *et al*. (2015) noted that fresh dates generally contain higher vitamin concentrations than dried dates, and that vitamins are depleted during prolonged drying and boiling due to leaching and thermal degradation. These findings collectively indicate that a brief boiling period may improve the extractability of certain fat-soluble and water-soluble vitamins from the rigid date seed structure, but that extended heating reverses this benefit.

The pronounced loss of folate and vitamin C during boiling aligns with established evidence on the heat sensitivity of these vitamins. Yuan *et al*. (2022) reported that blanching kale and spinach caused substantial losses of vitamin C, with loss rates of 3.60 mg/100 g per minute increase in blanching time and noted that vitamin C loss trends closely paralleled potassium loss, indicating a common leaching mechanism. In the present study, folate was significantly reduced in all boiled treatments relative to the control, consistent with the high heat lability of this vitamin. Vitamin C, however, exhibited a non-monotonic pattern with a peak at 60 min (10.61 mg/100 g). This rebound may reflect the release of bound ascorbate forms after initial leaching losses, although direct evidence for this mechanism in date seeds is lacking. The contrasting behavior of niacin, which increased progressively with boiling duration to 2.62 mg/100 g at 120 min, supports the well-documented hierarchy of heat stability among B vitamins. Samtiya *et al*. (2020) noted that niacin is considerably more resistant to thermal degradation than thiamine and riboflavin, which are significantly reduced by prolonged boiling. Alrosan *et al*. (2025) further observed that Maillard reactions during prolonged heating can reduce lysine availability and alter the apparent concentrations of heat-labile B vitamins.

Anti-nutrient Composition

The reduction of haemagglutinin from 5.39 HU/g in the control to 3.54 HU/g at 60 min is consistent with the general understanding that boiling effectively reduces lectin activity in plant foods. Samtiya *et al*. (2020) reviewed multiple processing strategies and confirmed that thermal treatments, particularly boiling, are among the most effective methods for reducing haemagglutinins and other heat-labile anti-nutrients in legumes and cereals. Maphosa and Jideani (2017) similarly concluded that boiling markedly improves the nutritional value of legumes by reducing lectins and haemagglutinins. Adeyemi *et al*. (2021) reported that hydrothermal processing of *Mallotus subulatus* caused significant decreases in phytic acid, saponin, and tannin, and eliminated trypsin inhibitor activity under pressure boiling. The significant reduction of oxalate at 60 min (6.55 mg vs. 7.73 mg in control) further supports the efficacy of hydrothermal processing in mitigating anti-nutrient load. Oraka and Okoye (2017) reported comparable oxalate reductions in boiled Lima bean, and Abu *et al*. (2020) observed significant decreases in oxalate, phytate, and tannin in processed *Sphenostylis stenocarpa* seeds.

The non-linear response of phytate, with a minimum at 30 min (0.389 mg) and a peak at 60 min (0.645 mg), warrants careful interpretation. Similar patterns have been reported in Djansang seeds, where phytate content decreased at intermediate boiling durations but increased again with prolonged heating (Nwuzoh *et al*., 2024). Ertaş and Türker (2014), as cited in Samtiya *et al*. (2021), noted that soaking and short cooking drastically decrease phytate, but prolonged cooking can increase its concentration through dry matter loss and the formation of insoluble phytate–protein–mineral complexes. The increase in measurable saponin at 60 min (11.43 mg vs. 9.17 mg in the control) is similarly plausible as a hydration-driven release phenomenon. Odufuwa *et al*. (2007) and Adeyemi (2020) reported that some processing methods increased measurable saponin in African star apple kernel due to hydration allowing water to penetrate the interior and release more saponins by simple diffusion. Zaid (2002, as cited in Al-Farsi, 2020) noted that date seeds gain approximately 25% weight after 72 h soaking, which supports the interpretation that hydration-driven matrix changes can increase the extractability of saponins during the early phases of boiling.

Tannins were not significantly affected by boiling duration in this study ($p = 0.292$), which contrasts with findings in some legume systems where thermal processing significantly reduces tannin content (Abu *et al*., 2020). However, Li *et al.* (2023) found that hot water dipping reduced tannins responsible for acrid taste to a minimum but did not eliminate them entirely. Al-Farsi *et al.* (2005) reported that date seeds contain approximately 3942 mg/100 g phenolics, with high levels of bound tannins in the seed coat that are resistant to leaching. This characteristic may explain the stability of tannins under the boiling conditions employed here. The anomalous increase in trypsin inhibitor activity at 120 min (0.092 TIU/mg vs. 0.046 TIU/mg in the control) is contrary to the

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well-established heat lability of protease inhibitors. Pugalenthi *et al.* (as cited in Abu *et al*., 2020) showed that boiling and roasting reduced trypsin inhibitor activity in *S. stenocarpa* due to protein denaturation. Ohanenye *et al.* (2022) noted that excessive heat can denature proteins into less digestible aggregates and that browning reaction products may interfere with colorimetric assays. The observed increase in the present study may therefore reflect assay interference from Maillard reaction products formed during prolonged boiling rather than a genuine increase in inhibitor activity.

Mineral Composition

The mineral data reveal two competing processes: leaching loss and enhanced extractability. Potassium peaked at 90 min (914.89 mg) before declining, a pattern consistent with the findings of Yuan *et al*. (2022), who reported substantial potassium losses during blanching of leafy vegetables, with loss rates of 5.00 mg/100 g per minute in kale and 12.17 mg/100 g per minute in spinach. Bethke and Jansky (2008), and more recently Al-Jaloud *et al*. (2020) and Ismail *et al*. (2020), confirmed that boiling reduces potassium, phosphorus, magnesium, zinc, manganese, and iron in plant tissues through leaching. The initial increase in potassium and several other minerals likely reflects matrix softening and improved extractability following cell wall disruption, while the subsequent decline indicates that leaching becomes dominant with prolonged exposure to the aqueous medium.

Manganese exhibited a progressive decline with boiling duration (17.52 to 10.43 mg at 90 min), consistent with leaching of water-soluble minerals into the cooking water. Phosphorus showed a more complex pattern, with a significant dip at 60 min (599.45 mg) but higher values at 30 and 90 min (828.61 and 829.00 mg, respectively), suggesting that the balance between leaching and matrix release varies with treatment duration. Magnesium and iron were not significantly affected, indicating relative heat stability or limited mobility under the conditions tested. The stability of magnesium is notable and aligns with observations in biofortified beans, where magnesium was less affected by soaking and boiling than other minerals (Kana *et al*., 2017). Hamza and Al-Hashimi (2023) and the UAE date variety study by Ismail *et al*. (2020) reported that heat treatment can increase measurable mineral content due to matrix softening and improved extractability, as also reported for winged bean where baking and boiling increased mineral availability by reducing phytate that chelates minerals (Samtiya *et al*., 2021). The reduction in phytate lowers bound minerals while enhancing free mineral contents, which may explain the increases in sodium, copper, and zinc at specific time points in the present study.

Proximate Composition

The significant reduction in crude fat from 4.61% in the control to approximately 2.1–2.3% in boiled samples is consistent with lipid leaching into the cooking medium. Nwuzoh *et al*. (2024) similarly reported that boiling significantly reduced crude fat in Djansang seeds, attributing the loss to lipid migration into the aqueous phase during thermal processing. The stability of protein, fibre, and ash across boiling durations indicates that these components are relatively heat-stable at 100 °C and are not substantially lost through leaching under the conditions employed. This finding is supported by Ogundana et al. (2020), who reported that crude protein in winged bean was 17.93% when baked and 19.59% when boiled, compared with 12.55% in the control, indicating that protein is heat-stable at 100 °C for short processing times. The significant decrease in carbohydrate content at 90 min (34.52%), accompanied by reduced energy values at 30 and 90 min (253.32 and 249.63 kJ, respectively), may reflect the combined effects of soluble solid leaching and the concentration of indigestible Maillard products that are not fully accounted for in the available carbohydrate fraction.

Fibre Fraction Composition

The fibre fraction data indicate that boiling duration significantly alters cell wall architecture. The increase in neutral detergent fibre at 90 min (89.44%) and acid detergent fibre at 120 min (56.80%) is consistent with the concentration of insoluble fibre components following the loss of soluble solids, as well as the possible formation of resistant starch and Maillard products that are recovered in fibre fractions. Adeyemi (2021) and Karimi *et al*. (2012) reported that steam treatment of date leaves significantly affected cell wall components, decreasing NDF but increasing ADL, with maximum changes observed in hemicellulose. The significant decrease in acid detergent lignin and lignin at 60 min (7.45% and 0.98%, respectively, vs. 9.77% and 2.22% in the control) suggests partial solubilization of lignocellulosic bonds, which would be expected to improve digestibility. This finding is practically relevant, as date seeds have traditionally been soaked and boiled before incorporation into ruminant feed to enhance nutrient accessibility (Zaid, 2002, as cited in Al-Okbi, 2022). The peak in hemicellulose at 90 min (40.74%) and the inverse relationship between hemicellulose and cellulose at 120 min (20.25% and 46.19%, respectively) indicate that the fibre matrix undergoes dynamic reorganization during prolonged boiling. These changes likely reflect the differential solubility and degradation of cell wall polysaccharides under sustained thermal and hydrating conditions.

Limitations and Implications

Several limitations should be acknowledged. The study employed a single date seed variety and three replicates per treatment, which limits the generalizability of the findings. The mechanisms proposed for the non-monotonic responses of certain vitamins, anti-nutrients, and minerals, particularly the rebound effects observed for vitamin C, saponin, and phytate are inferential rather than directly demonstrated. Future work should consider expressing all compositional data on a dry matter basis to disentangle genuine changes from concentration effects and should include direct assays of leaching losses in the cooking water. The anomalous trypsin inhibitor results warrant verification using alternative assay methods that are less susceptible to interference from browning reaction products.

Despite these limitations, the data support a practical recommendation: boiling for 30 to 60 min appears to offer a favorable balance between enhancing the extractability of certain vitamins, reducing heat-labile anti-nutrients such as haemagglutinin and oxalate, and partially solubilizing lignin to improve digestibility, while avoiding the more severe losses of folate, riboflavin, and minerals observed at longer durations.

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