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Enhancement of Beef Burgers Using Date Palm Seed Powder to Improve Quality Characteristics During Frozen Storage

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Abstract: This study assessed the effects of 2% (T2) and 4% (T3) date palm seed powder (*Phoenix dactylifera* L., cv. Halawi) on the physicochemical, microbiological, and sensory attributes of beef burgers during 30 days' frozen storage at -18 °C compared to the negative (T1) and positive (T4: 0.02% BHT) controls. Adding DSP powder to the burgers resulted in a significant reduction ($P < 0.05$) in cooking loss and ensured pH stability during storage. The chemical indices of oxidation were strongly reduced in DSP samples with T3 showing significantly lower TBARS values (0.23 mg MDA/kg) and FFA (0.23%) at day 30 over T1 (0.32 mg MDA/kg and 0.44%, respectively). From the microbiological aspect, DSP inclusion had a major impact on the inhibition of TVC, psychrophiles, and *E. coli* during the 30-day storage period compared with T1. The sensory results showed T3 receiving better ratings for color, taste, tenderness, juiciness, and total acceptability. Generally, the 4% DSP powder acted as a natural antioxidant and antimicrobial compound, thereby enhancing the quality attributes, stability, and shelf life of frozen beef burgers.

Keywords: Beef burger, date palm seed, antioxidant, antibacterial

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Introduction

The consumption of meat is critical for the human diet because it is an excellent provider of proteins, amino acids, and nutrients. However, owing to its high moisture content and nutritional value, meat is highly perishable due to the effect of microorganisms and oxidation processes (17, 34). Such perishability is particularly high for ground meat products like burgers since the process of grinding spreads surface microflora over the entire meat patty and making lipids and hemoproteins available for oxidation (34), turning the meat rancid and resulting in exudation and spoilage due to the action of microorganisms and/or lipids (28). Freezing at −18 °C slows down the processes but cannot prevent them completely since lipid hydrolysis and oxidation still occur in frozen meat and are interconnected (21, 28, 36). To prolong product shelf-life and reduce rancidity, manufacturers resort extensively to BHT and BHA. However, with time, questions regarding their safety, especially in terms of toxicity or potential carcinogenicity, have prompted researchers and consumers to seek natural additives extracted from plant sources (2, 21).

The use of bioactive compounds from plant by-products as natural preservatives has thus attracted interest due to their antioxidants and antimicrobial characteristics, along with other health benefits (6, 14, 16). Date palm seeds, in particular, are one of such potential candidates. As a cheap, sustainable source, usually discarded after its main purpose, the seed contains many phenolic compounds, flavonoids, polysaccharides, and dietary fibre, which contribute to their antioxidative and antimicrobial properties (11, 19, 27, 31). Their versatility has been amply proven, with date seed fiber enhancing the functionality of turkey burger (15), while its protein concentrate has been modified to promote its functionality (27). The date palm has also been recognized as an important contributor to sustainability in food security and economic development in that its "Flesh and seeds contain biologically active compounds and thus can serve as functional foods for health promotion" (20). Polyphenols in the seeds increase the antioxidant value of foods while decreasing waste, which supports sustainable food production (31), and consumption of the powder has antioxidant properties and controls blood sugar (31).

In vitro antibacterial properties have been found in the extracts of date seeds (7, 25), while the use of date palm plant wastes/by-products is part of the circular bioeconomy (30). Studies conducted recently showed that bioactive biopolymer coatings containing date seed cellulose nanocrystals and polyphenols had antioxidant and antimicrobial properties that help preserve the quality of meat by delaying lipid oxidation and microbial deterioration (29). Antioxidant potential, on the other hand, varies greatly. Date pit flour, according to (34), had 9.17 g gallic acid equivalents (GAE) per 100 g, while date seed flour had 2.53 mg of phenolics per gram (28), which is about 36 times different if both values were converted to GAE. Date seed powder has also been observed to increase the shelf life, reduce bacteria numbers, and improve the color, flavor, tenderness, and juiciness of meat as well as shorten tenderization time (10). Garden cress, a similar seed powder, for instance, decreased lipid oxidation and increased the acceptability of beef burgers (9).

The four existing experiments on the effects of date seeds can be considered close precursors to the proposed study and raise a particular question each. (34) supplemented beef burgers kept at 4 °C for 10 days with 0, 1.5, 3, and 6% of date

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pit powder. The findings showed that the 3% dosage resulted in maximum protection of color, lipid oxidation, and microbial proliferation and maintained psychrotrophic counts at almost 2 log CFU/g below the control, while 6% decreased the acceptability of cooked burgers (4.5 against 5.5 on the 7-point scale). Their burgers were chilled, not frozen, untreated by BHT and they did not perform an analysis of free fatty acids. (28) applied 1-10% date seed powder in beef and chicken burgers noting that peroxide values were invariably lower in beef meat products, while TBARS values exhibited dose dependence (just 3% and 10% suggested positive effects), while the results for chickens were inconclusive, thus leaving the best inclusion level undefined. (1) added 0–16% powder to beef meatballs and found that phenolics and antioxidants increased with higher inclusion levels, while cooking properties improved without any changes in sensory characteristics. However, they did not test the resistance of the product to spoilage, and even their lowest tested level (4%) was high enough. (19) used the chemically modified soluble fibre from date seeds together with gelatin as a fat substitute (gel powder - 20%) in beef burgers, though they did not investigate the storage stability of the product, and found that the acceptability of gel-containing burgers (8.19-8.50 on a ten-point scale) was inferior to that of the control samples (8.45-8.81).

Taken together, these studies create three specific research gaps. First, to the best of our knowledge, none considered date seed powder in frozen burgers against a control group with an artificial antioxidant: (34) mentioned BHT being the reason for conducting the experiment but did not use it as the reference compound, which creates uncertainty as to whether a low amount of powder can rival the additive it replaces under −18 °C conditions used in commercial burgers.

This work, therefore, examines the effects of the addition of date palm seed powder as a natural antioxidant and antimicrobial agent in beef burgers. The specific objective was to determine whether it retarded fat oxidation, inhibited microbial growth, and improved the quality attributes of burgers at −18 °C frozen storage.

Materials and Methods

Date Palm Seed Powder

Fully matured Halawi dates (*Phoenix dactylifera L*) were obtained from local markets in Basra in January 2026. They were manually separated from the date flesh, washed, dried, and ground using an electric grinder until a fine powder was obtained. The powder was then stored in airtight glass bottles pending experimental analysis.

Chemical Composition of Date Palm Powder

The approximate chemical composition of the date palm seed powder samples (moisture content, crude protein, crude fat, ash, and fiber) was determined, while total carbohydrates were calculated by difference based on the methods described by (16). Additionally, bioactive compounds content, specifically total phenolics (TPC) and total flavonoids (TFC), was estimated spectrophotometrically, while antioxidant activity was evaluated using the DPPH radical scavenging and ferric reducing antioxidant power (FRAP) assays, following the methodology and laboratory conditions specified in (16).

Beef Burger Preparation

The beef thighs were sourced from a local market in the Basrah Governorate from cows aged approximately 1.5 to 2 years, and was stored in the fridge at 4 °C for one day. The next day, beef samples were subjected to fat content standardization by removing all fat and then adding them back to achieve a final concentration of 15% (adding 15 g of fat to each 85 g of meat). After all the fat had been removed, the beef was comminuted using a commercial electric grinder, minced again and 1.5% salt added. The beef was then divided into four portions comprising the control (T1), and with 2% (T2) and 4% (T3) date palm seed powder, while T4 (positive control, supplemented with 0.02% w/w) synthetic antioxidant, butylated hydroxytoluene [BHT]. All treatments were prepared in three independent formulation batches using a single, homogenized lot of raw beef to ensure process repeatability.

Chemical Tests

The method developed by (18) was used to determine the free fatty acid (FFA) content in meat, where 50 ml of ethyl alcohol at 98% concentration was heated to a boil in a glass. FFA was determined using about 3 g of the comminuted beef sample. A few drops of phenolphthalein were added to the mixture. A potassium hydroxide solution was used with a normality of 0.1 to titrate the mixture, and the solution changed to a bright pink color when this occurred. The percentage of FFA was calculated using the formula:

$$\text{Free Fatty Acid \%} = \frac{(\text{Titration (A}-\text{B)} \times \text{n} \times 282 \times 100)}{(1000 \times \text{weight of sample in grams})}$$

Where, A = ml of KOH used for the fat or oil sample, B = ml of KOH used for the blank, 282 = molecular weight of oleic acid, n = normality of KOH (0.1N)

The TBARS method (thiobarbituric acid reactive substance), was utilized for monitoring lipid oxidation in beef burgers. It involves steam distillation and spectrophotometry, done according to the procedure described by (26). A 10g homogenous sample was combined with distilled water at 47.5 ml, and then acidified with 2.5 to 3 ml of 4N HCl. Then steam was distilled with 2ml of paraffin and a boiling stone, and a 50 ml portion was separated from the resultant distillation. A 5ml aliquot of the distillation was mixed with 5ml of the TBA reagent solution. The TBA reagent solution consisted of 0.2883g TBA dissolved in 90% acetic acid. The volume was made up to 100ml. The tubes were then sealed tightly and placed inside the water bath at 95–100 °C for 30 minutes, and then cooled. A reagent blank was used as a reference and absorbance was recorded at 532nm. For the calibration curve, a hydrolyzed TEP standard was prepared, and processed in the same manner. TBARS was expressed in units of mg of malondialdehyde (MDA) per kg of meat, as per the following formula:

$$\text{TBA (mg/kg meat)} = 7.8 \times \text{Absorbance}$$

Bacteriological Tests

For counting the psychrotrophic and total bacteria, the pour plate technique was employed using nutrient agar. After preparing the serial dilution, it was incubated for 24 to 48 hours at 37 °C to determine the total number of bacteria. The plates holding the psychrotrophic bacteria, however, were placed in the fridge at 4 °C for ten days.

Enumeration of E. coli Bacteria

E. coli counts were estimated using the method of (35), with some modifications. Representative 10 g samples of burger patties were collected under aseptic conditions and mixed with 90 mL of sterile 0.1% Buffered Peptone Water to obtain the initial dilution (10^{-1}). Subsequent serial decimal dilutions were then prepared. MacConkey Agar medium was prepared by dissolving 51.5 g in one liter of distilled water according to the manufacturer's instructions and was sterilized by autoclaving at 121 °C for 15 minutes. The pour plate technique was employed by transferring 1 ml of the appropriate dilutions into sterile Petri dishes, followed by pouring the medium (cooled to 45 °C). After the medium solidified, the plates were incubated in an inverted position at 37 °C for 24–48 hours. Colonies appearing pink to red and surrounded by a halo of precipitated bile salts (indicating lactose fermentation and characteristic of *E. coli*) were counted, and results were expressed as colony-forming units per gram (CFU/g).

Determination of pH

The pH value was determined using a pH meter, following the method of (34).

Determination of weight loss during cooking

This was calculated by grilling minced meat patties on a laboratory hot plate for six minutes flipping them after three minutes to ensure an internal temperature of 70 °C in accordance with the following equation:

Cooking loss (%) = [(Initial weight − Final weight) / Initial weight] × 100 (23)

Sensory Evaluation

A panel of ten members (5 males and 5 females) aged 25-45 years assessed the burgers for their color, flavor, tenderness, juiciness, and overall sensory properties on a nine-point descriptive scale (1 (extremely poor), through 5 (neither like nor dislike), to 9 (extremely good)). They underwent training through three two-hour sessions prior to testing. The samples were uniformly cut and offered hot at (50 – 55 °C) in numbered 3-digit plates using randomized block design (32). The panelists were supplied with warm drinking water (about 37-40 °C) and salt-free crackers for palate cleansing and removal of any remaining fats/flavors between samples.

Statistical Analysis

The experiment was conducted using a completely randomized design (CRD), while SPSS software was applied to analyze the data. Version 24 2016. LSD, at $P<0.05$, was used to compare the means. All tests were conducted in triplicate. Date was statistically analyzed using IBM SPSS Statistics for Windows, Version 24.0 (24).

Results and Discussion

Analysis of the Halawi date seed powder (Table 1) revealed high levels of dietary fiber (71.40%) and total carbohydrates (86.96%), alongside low moisture content (7.17%) a factor that enhances the powder's storage stability and protects it against microbial spoilage (3). The results also demonstrated significant levels of total phenolic compounds (5.88 mg GAE/g DW) coupled with high antioxidant activity, evidenced by 68.4% DPPH radical inhibition and an iron-reducing power (FRAP) of 17.19 mg TE/g DW. These findings underscore the high functional value of date seeds as a promising food additive and a natural source of antioxidants (16, 22).

Figure 1 illustrates the effect of the date palm seed powder on TBA values. Its addition at the T2 and T3 concentrations significantly reduced the TBA value in the frozen beef burgers after the 30-day storage period at -18 °C. The control samples of T1 had a TBA value of 0.32 mg/kg and T4 had 0.29 mg/kg, but T2 and T3 had lower values at 0.25 mg/kg and 0.23 mg/kg, respectively. This indicates that the addition of extra date seed powder acted as a stabilizer in the burger samples, thereby retarding the rates of fat oxidation. T2 and T3 samples demonstrated the highest efficacy in inhibiting the oxidation of lipids in the burger samples during frozen storage. This aligns with the findings by (28). The findings revealed that the moderate to higher concentration of date seed powder addition was more effective in inhibiting oxidation than the lower concentration or the non-treated samples. The study indicates that the date seed powder adds to the oxidative stability without affecting the quality of the burger. The high levels of bioactive compounds, primarily phenolic compounds and flavonoids, present in the powder are responsible for its strong antioxidant activity in T2 and T3 treatments. These natural antioxidants play a key role in combating free radicals and effectively inhibit the oxidation of lipids. This delaying action causes a slowdown of the malondialdehyde buildup that the TBA test detects.

Other studies (16, 33, 34) have reported similar effects using date seed powder. Although the overall values of TBA were lower for the treatments, TBA values continued to increase with prolonged storage time for all groups. This is because the lipids continue to form and degrade, resulting in an accumulation of malondialdehyde and other secondary lipid oxidation products. (36) also made the same point that lipid oxidation continues even inside the freezer, albeit at a reduced rate. According to (39), this continuous lipid oxidation has a significant effect on the quality of the meat and meat products. Based on the overall results, this study suggests that the application of date seed powder at T2 and T3 concentrations is an effective combination for achieving the best balance between antioxidant ability and resistance of the frozen beef burger to oxidation. Hence, the application of date seed powders could be an effective natural substitute for the synthetic antioxidants used in frozen meat products, owing to the trend in natural food additives.

Thus, the addition of the date seed powder at the T2 and T3 levels effectively provides an effect, providing frozen beef burgers with an optimal blend of antioxidant properties. In summary, date seed powder serves as a viable natural antioxidant against oxidation and appears to be a promising option for those who wish to forgo additives.

Lipid oxidation (TBA). Within the first 30 days of frozen storage, TBA values decreased from 0.32 mg/kg in the control sample (T1) to 0.25 mg/kg at 2% (T2) and 0.23 mg/kg at 4% (T3) — a decrease of 22% and 28%, respectively. This is a relatively clean and consistent dose-response relation compared to what (28) observed in the case of beef burgers, where "the improvements in the oxidative stability were found to be inconsistent from 1% to 10%" and "potential effect" was shown only for 3% and 10%, whereas chicken burgers in this study had absolutely no consistent dose-dependent pattern at all. However, this effect is consistent in terms of the trend (although produced under harsher storage conditions) with

Table 1. Physicochemical, proximate composition, and phytochemical characterization of *Halawi* date seed powder.

Parameter/Parameter Class	Unit/ Expression	Value (Mean ± SD) *
Cultivar & Physical Properties		
Date Palm Cultivar	—	*Halawi* (*Phoenix dactylifera* L.)
Drying Conditions	°C / time	Oven-dried at 60 °C for 24 h
Particle Size	µm / Mesh	250 µm (sieved via 60-mesh)
Proximate Composition		
Moisture Content	%	7.17 ± 0.34
Crude Protein (N * 6.25)	% dry weight	4.59 ± 0.21
Crude Fat (Ether Extract)	% dry weight	7.30 ± 0.40
Ash Content	% dry weight	1.15 ± 0.07
Crude / Dietary Fiber	% dry weight	71.40 ± 1.14
Total Carbohydrates (by diff.)	% dry weight	86.96 ± 1.11
Bioactive Compounds & Antioxidant Capacity		
Total Phenolic Content (TPC)	mg GAE / g DW	5.88 ± 0.40
Total Flavonoid Content (TFC)	mg QE / g DW	0.20 ± 0.03
DPPH radical scavenging activity	mg TE / g DW	26.55 ± 0.24
DPPH inhibition percentage	%	68.4% ± 1.15
Ferric reducing antioxidant power (FRAP)	mg TE / g DW	17.19 ± 0.37

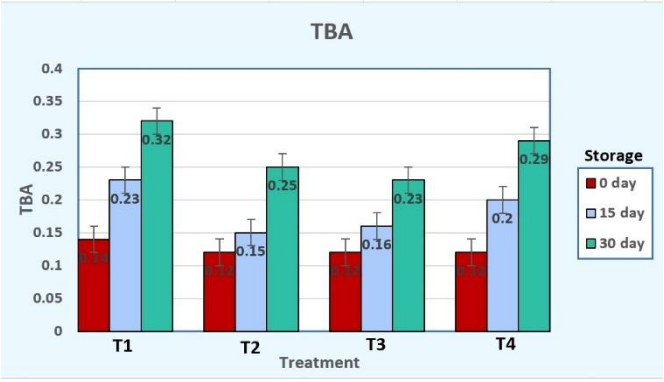


Figure 1. Effect of using date palm seed powder on TBA in frozen beef burgers
LSD treatment & day=0.02. T1: control treatment; T2: 2% date palm powder; T3: 4% date palm powder, T4: BHT.

(34), who noted that addition of date pits to the burger mixture substantially inhibited pigment oxidation and prevented metmyoglobin formation. Its level in the control sample after 10 days storage at refrigeration temperature amounted to 51.0%, while the samples containing date pit powder showed 9.8–16.0% of metmyoglobin on day 0 of storage.

Figure 2 reveals that including date palm seed powder into beef burgers strongly reduces FFA content during frozen storage at -18 °C. From the beginning, T1 had higher levels of FFA followed by T4 compared with the samples containing date seeds, T2 and T3. During freezing for 30 days, FFA increased in all samples, though it was considerably lower for T2 and T3, at 0.27% and 0.23%, respectively, compared with the control's 0.44%. T2 and T3 did not accumulate much FFA, so they maintained lipid degradation during the frozen storage process. As noted by (16), adding date seed powder can prevent lipid breakdown in food as the powder is rich in antioxidants. Furthermore, polyphenolic compounds and flavonoids in date seed powder prevent the breakdown of fat molecules by enzymes like lipase, thereby reducing free fatty acid. However, that is not the only reason why date seed powder works, as the antioxidants it contains can actually preserve the structure of fat in meat. According to (2, 28), antioxidants in plants protect triglycerides from being attacked by enzymes and oxidation. This means that when antioxidants are added to meat, the fat molecules in meat will be less likely to be broken down though this only occurs when the right quantity is used. Hence, it is not surprising that T2 and T3 had lower levels of FFA than the control. The increase in FFA in the control treatment was much higher, mainly because the enzymes, like phospholipase and lipase, had nothing to hold them back and they rapidly hydrolyzed the fat in the meat, as also mentioned by (36).

Since the control samples did not contain any antioxidant compounds, these two enzymes were constantly breaking down lipids, resulting in an accumulation in the levels of FFA. However, when the date palm seed powder was introduced, along with the concentration of both T2 and T3, the situation changed altogether. Lipid hydrolysis was reduced, and the lipid level of the frozen beef burger meat remained quite stable. These data correspond with previous studies and confirm the previously mentioned theory that date seed powder has the potential to act as an antioxidant.

Free fatty acids (FFA). FFA in the control group increased to 0.44% on day 30, while those in groups T2 and T3 were 0.27% and 0.23% or a reduction of 39% and 48%, respectively. (19), who carried out a study where DSP was used as a fat replacer in the broader range of 1–10%, found a dose-dependent yet not monotonous relationship with only their 3% and 10% groups displaying clear stabilization during the period of storage. In this case, however, the narrower range of 2–4%, chosen for the study in order to assess the use of DSP as an antioxidant rather than fat replacer, produced a more predictable dose-response relationship.

Figure 3 illustrates the same results for bacteria. It is clear that the control treatment has a total bacterial count (63.9×10^3 CFU/g) that is substantially higher than for the burgers containing date palm seed powder. However, treatments T2

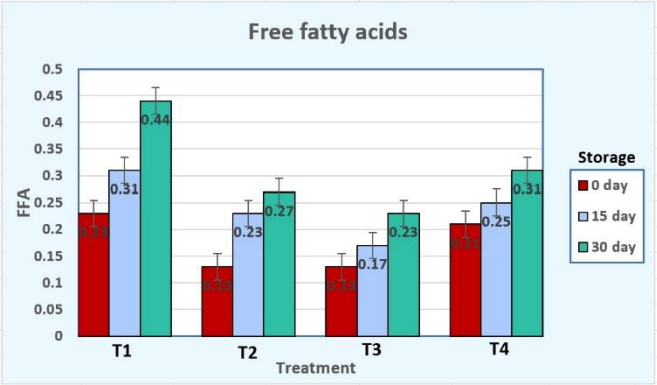


Figure 2. Effect of using date palm seed powder on free fatty acids (FFA) values in frozen beef burgers
LSD treatment & day=0.01. T1: control treatment; T2: 2% date palm powder; T3: 4% date palm powder, T4: BHT.

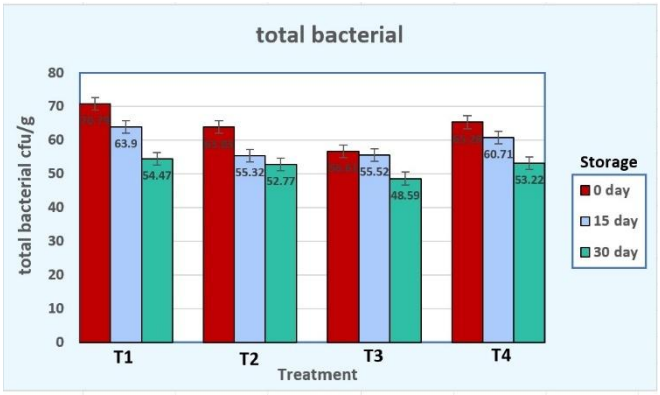


Figure 3. Effect of using date palm seed powder on total bacterial count in frozen beef burgers
LSD treatment & day=5.17. T1: control treatment; T2: 2% date palm powder; T3: 4% date palm powder, T4: BHT.

and T3 showed a decrease to 55.32 × 10³ CFU/g and 55.52 × 10³ CFU/g, respectively, after 15 days of freezing, indicating that the date seed powder significantly reduced microbial growth in frozen beef burgers. Treatments T2 and T3 had fewer bacterial counts due to the presence of antimicrobial and antioxidant activity in date palm seed powder. Substantial literature evidence supports this finding, and date seed powder has been shown to possess biologically active compounds like phenolics, flavonoids, and tannins which effectively inhibit spoilage progression and detrimental bacterial activity (7, 36). These hinder basic microbial activities, hence increasing the shelf life of the processed meat. Additionally, total microbial count decreased during the freezing time, starting with a mean microbial population of 70.97 × 10³ CFU/g on day zero, to 54.47 × 10³ CFU/g after the 30th day The freezing process affects bacteria negatively by reducing their metabolic activity, together with the enzymes needed by bacteria for cell division. Apparently, this is not enough, since the date seed powder also has an increased effect on this factor as well. The phenolic content, together with tannins, interferes with the bacterial cell membrane, hence increasing membrane permeability, which impairs bacterial cell division (1). The date palm seed powder is an organic preservative of meat.

As noted by (1), incorporating plant-derived antioxidants having antimicrobial properties effectively suppresses bacterial activity and extends the shelf life of meat products. Consistent with these observations, this study demonstrated that enriching frozen beef burgers with date seed powder significantly reduced microbial activity compared to the untreated control. The conclusion is that the use of the powder, especially for T2 (52.77 × 10³ CFU/g) and T3 (48.59 × 10³ CFU/g), is highly effective in reducing bacterial activity and preserving the safety of the frozen beef burger for a much longer period of time.

Microbial counts. Total bacteria count decreased from 63.9 x 10³ CFU/g (control) to 55.32 x 10³ and 55.52 x 10³ CFU/g for 2% and 4%, respectively, after 15 days of exposure (13-14% decrease). These outcomes declined further to 54.47, 52.77, and 48.59 x 10³ CFU/g (T1, T2, and T3, respectively) after 30 days. (34) found a stronger impact of DSP on psychrotrophic bacteria (2 log CFU/g lower with 3% date pit powder compared to the control after 10 days of refrigerated storage). However, this result cannot be compared to the present CFU/g results, since it involved a different group of bacteria, measured in logarithmic scale, and obtained during refrigeration storage, where the speed of microbial growth is considerably lower than during freezing.

Counts of psychrotrophic bacteria declined for all the treatments during the storage period when samples were kept in the freezer at −18 °C (Figure 4). In the control (T1), it decreased from 54.91 × 10³ CFU/g on day 0 to 44.81 × 10³ on day 15 and to 40.60 × 10³ on day 30. In T2 (2% date seed powder), it fell from 49.29 to 41.08 and then to 36.74 × 10³ CFU/g. In T3 (4% date seed powder), it reduced from 46.52 to 37.29 and then to 34.07 × 10³ CFU/g while in T4 (BHT), it was 52.01 to 43.21 and then to 38.54 × 10³ CFU/g.

The control had the highest values for all storage periods while T3 had the lowest values, followed by T2. The difference between the control (T1) and T3 (8.39, 7.52 and 6.53 × 10³ CFU/g on days 0, 15 and 30 respectively) was larger

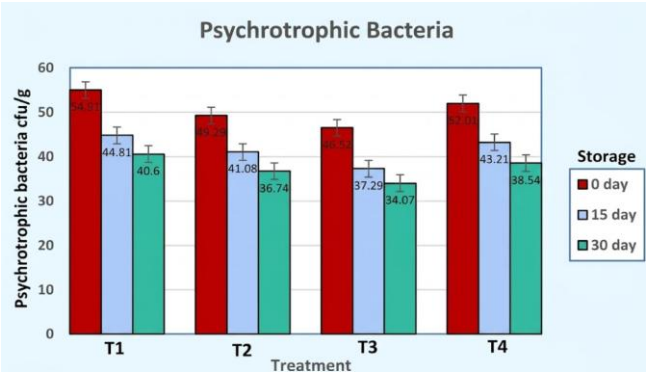


Figure 4. Effect of using date palm seeds powder on psychrotrophic bacteria counts in frozen beef burgers
LSD treatment & day=3.73. T1: control treatment; T2: 2% date palm powder; T3: 4% date palm powder, T4: BHT.

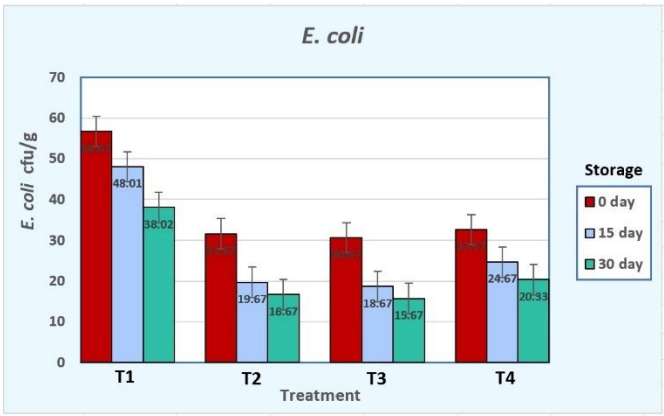


Figure 5. Effect of date palm seed powder on *E. coli* bacterial counts in frozen beef patties after different periods of storage
LSD treatment & day=3.65. T1: control treatment; T2: 2% date palm powder; T3: 4% date palm powder, T4: BHT.

than the LSD (3.73) for all three periods. The difference between the control (T1) and T2 (5.62, 3.73 and 3.86 × 10^3 CFU/g) differed by day 1.

As shown in Figure 4, the addition of date seed powder in frozen beef burgers was responsible for reduced counts of psychrotrophs, with a more pronounced effect for T3 (4%) compared to T2 (2%). The counts after 15 days storage were 41.08 × 10^3 CFU/g in T2 and 37.29 × 10^3 CFU/g in T3, while for the control samples it was 44.81 × 10^3 CFU/g. For 30 days of storage, the counts were 36.74 and 34.07 × 10^3 CFU/g in T2 and T3 respectively, compared to 40.60 × 10^3 CFU/g in controls.

This may be because of the presence of bioactive compounds in date seeds which are known to have high amounts of phenols, flavonoids, and other metabolites with antimicrobial properties, including antibacterial properties against psychrotrophs (4, 7). These compounds are capable of damaging the bacterial cell walls, change the permeability of cell membranes, and inhibit metabolic pathways, making their survival difficult in cold temperatures. Such results were also obtained by (25)**,** who observed that the presence of phenolic compounds from plant waste products, such as date seed extract, restricted the growth of the psychrotrophic bacteria found in meat even after prolonged freezing.

Two important points need to be noted about the results. First, the counts decreased in the control group as well (from 54.91 to 40.60 × 10^3 CFU/g), thus indicating the effect of freezing. Second, the initial counts in T2 and T3 groups were lower than the control and their decrease over 30 days of freezing was the same as in the control group (25-27% in all treatment groups). Thus, part of the differences among the treatments existed before the experiment started. The T4 (BHT) treatment group did not differ consistently from the control. This can be expected as BHT acts primarily as an antioxidant but not an antimicrobial.

To summarize, date seed powder, particularly at 4%, was associated with lower psychrotrophic bacteria counts in frozen beef burgers

The results in Figure 5 show a continuous reduction in the number of *E. coli* bacteria over longer storage times for all treatments. On day 0, the highest *E. coli* numbers were recorded in T1 (56.67 CFU/g), whereas in T2, T3, and T4 they were 31.67, 30.67, and 32.67 CFU/g, respectively. The initial low counts of *E. coli* found in T2, T3, and T4 compared to T1 on day 0 are due to the immediate effect of the antimicrobial activity of the added additives (date palm powder and BHT) during the process of mixing samples compared to the control treatment. After 30 days, the final counts were 38.02, 16.67, 15.67, and 20.33 CFU/g in T1, T2, T3, and T4, respectively.

Percentage-wise, the largest decline was in T3 (48.9%), followed by T2 (47.4%), T4 (37.8%), and T1 (32.9%). This might be related to long-term storage time and conditions present in each treatment. It has been shown previously that *E. coli* survival during storage depends upon several conditions, including temperature, pH, water activity, and food composition (5,12, 13), as well as the formulation of meat matrices with natural antimicrobial extract. Overall, this study showed a steady decline in *E. coli* counts for the 30-day storage period across all four treatments. T3 exhibited the lowest

number of bacteria at the end of the storage (15.67 CFU/g), followed by T2 (16.67 CFU/g), T4 (20.33 CFU/g), and T1 (38.02 CFU/g). Reduction in the number of bacteria was highest for T3 (48.9%) and lowest for T1 (32.9%). This suggests that both storage periods as well as the conditions applied in different treatments may have contributed significantly to the reduction of the number of *E. coli*. However, the presence of *E. coli* at the end of 30 days storage period suggests that no elimination of this bacterium took place due to storage.

Storage time significantly affected ($P<0.05$) the pH of beef burgers (Table 2). The overall mean pH increased from 5.56 ± 0.02 on day 0 to 5.84 ± 0.11 on day 15 and 5.88 ± 0.17 on day 30. The pH readings for all treatments on day 0 were nearly similar (5.53–5.58).

There were differences in overall mean pH among the treatments. The highest was the control (T1) at 5.87 ± 0.24, followed by T2 (2% date seed powder) at 5.76 ± 0.16, T4 (BHT) at 5.72 ± 0.14, and T3 (4% DSP) at 5.67 ± 0.13. The pH of the control increased steadily from 5.58 ± 0.02 on day 0 to 5.93 ± 0.11 on day 15 and 6.11 ± 0.09 on day 30. T2 and T3 also increased but to a lesser extent, reaching 5.91 ± 0.06 and 5.79 ± 0.01 on day 30, respectively. The pH of T4 increased to 5.88 ± 0.03 on day 15 and then decreased to 5.70 ±0.02 on day 30. The increase in the pH level with respect to time may be explained by biochemical and microbial reactions taking place during the storage process. This involves the breakdown of proteins into basic nitrogen-containing molecules such as ammonia and amines.

The pH values observed for the various treatments at the beginning were nearly similar to each other, indicating that the addition of date seed powder did not influence the initial pH of the burgers. This finding is consistent with the results presented by (34).By the end of storage, pH levels were notably lower in all treatments compared to the control, which reached a peak of 6.11. Among the formulation groups, the 4% date seed powder treatment (T3) demonstrated the minimum pH value.

Both storage time and treatments had a significant effect on cooking loss ($P<0.05$) which generally increased from 25.27 ± 0.20% on day 0 to 32.05 ± 1.46% on day 15 then declined slightly to 31.61 ± 0.45% on day 30 (Table 3). On day 0, values were very similar among all the treatments (25.09-25.52%).

The overall mean cooking loss varied for different treatments, with T1 (control) registering the highest value (30.22 ± 3.85%) followed by T4 (BHT) at 29.83 ± 3.57%, T2 (2% date seed powder) at 29.70 ± 3.31%, and the lowest for T3 (4% DSP) at 28.81 ± 2.17%. T4 and T2 did not differ significantly from each other. The control increased from 25.12 ± 0.12% on day 0 to 33.32 ± 0.01% on day 15 then declined to 32.22 ± 0.001% on day 30. A similar trend in cooking loss was observed for T2 and T4, which began increasing from 25.28 ± 0.12% to 32.52% and 32.61%, respectively, then decreased on day 30 (31.22% and 31.80%). T3 increased gradually from 25.52 ± 0.09% on day 0 to 29.73 ± 0.23 % on day 15, reaching 30.19±0.16 on day 30.

Higher cooking loss from storage could be associated with changes in the water-binding ability of the beef burgers during frozen storage and cooking. As mentioned earlier, during cooking, protein denaturation and protein contraction cause the exudation of water and fat, resulting in weight loss. Similarly, storage caused an increase in cooking loss of beef burgers, as stated by (38).

The lowest mean cooking loss was observed in the 4% date seed powder treatment (T3), while the highest was in the control group. This could be attributed to the effect of DSP on the moisture-binding properties of the burger matrix. The fiber component in DSP binds water and interacts with the meat proteins, thus improving water retention during cooking. This corroborates the findings of (8) who noted that adding date powder influenced cooking loss and yields of beef burgers. This is in line with (37) who stated that addition of water-binding ingredient to beef patties resulted in increased cooking yields and losses. It indicates that the benefit is based on the concentration and is observed only at the higher concentration level (4%).

In summary, both date seed powder and freeze duration influenced the cooking loss of the beef burgers. Differences between the treatments can be explained by variances in moisture holding and structure of the beef burgers.

Table 4 illustrates that the addition of date palm seed powder generally improved the appearance of beef burgers even after freezing. The color values for burgers were higher for those with powder than for those without. T3 had the best value at 8.49, followed by T2 (8.15), against 7.16 for the control group. This phenomenon is most likely due to antioxidants in DSP that slow the rate of some chemical reactions responsible for discoloration throughout storage. However, at the end of the storage period, even the color values for the DSP treatments declined significantly. This is due to changes in myoglobin into metmyoglobin during storage - a less appealing pigment. (36) observed a similar trend and noted that such pigment oxidation is among the most important factors affecting the appearance of stored meat.

Apart from being more colorful, burgers made with date palm seed powder also tasted better. DSP prevents fat breakdown, allowing positive flavor to be retained and eliminating any peculiar flavor. Essentially, the presence of antioxidants found naturally in date seeds reduces levels of peroxide and those unwanted compounds that affect meat flavor negatively (2, 19). On matters of tenderness, burgers made using DSP performed even better. While tenderness was measured at 7.39 for burgers in the control sample, it was higher, at 7.57 and 7.67, for T2 and T3, respectively. This can be attributed to DSP, which retains water, meaning that meat does not dry easily when being cooked but simply turns out more tender. This was also observed by (28), who used fiber-rich plant material to make meat more tender. However, juiciness essentially followed the same trend, where T2 and T3 were juicier compared to the control. This is due to enhanced water retention in the muscles. The bioactive compounds, fibers, and powders in DSP facilitate this process.

The relationship between tenderness, juiciness, and meat quality has also been noted (1) by other investigators. Combining all factors together, namely color, taste, tenderness, and juiciness, burgers formulated with DSP achieved significantly higher overall sensory scores and acceptability. These meat products received the highest ratings for overall acceptability, which indicates, to some extent, that these products are not just shelf-stable, but are enhanced by the presence of DSP. This has been shown to be the case by others (2, 9) who discovered that natural antioxidants in plant

Table 2. Effect of using date palm seed powder on pH of frozen beef burgers

pH					
Mean	**T4**	**T3**	**T2**	**T1**	**Treatment Day**
5.56^{c}±0.02	5.57±0.01	5.53±0.02	5.56±0.01	5.58±0.02	0
5.84^{b}±0.11	5.88±0.03	5.71±0.08	5.82±0.07	5.93±0.11	15
5.88^{a}±0.17	5.70±0.02	5.79±0.01	5.91±0.06	6.11±0.09	30
	5.72^{c}±0.14	5.67^{d}±0.13	5.76^{b}±0.16	5.87^{a}±0.24	Mean

LSD (day=0.05, day & treatment=0.12, treatment =0.08). T1: control treatment; T2: 2% date palm powder; T3: 4% date palm powder, T4: BHT

Table 3. Effect of using date palm seed powder on weight loss during cooking in frozen beef burgers

Weight loss during cooking					
Mean	**T4**	**T3**	**T2**	**T1**	**Treatment Day**
25.27^{c}±0.20	25.09±0.02	25.52±0.09	25.36±0.03	25.12±0.12	0
32.05^{a}±1.46	32.61±0.14	29.73±0.23	32.52±0.003	33.32±0.01	15
31.61^{b}±0.45	31.80±0.06	30.19±0.16	31.22±0.01	32.22±0.001	30
	29.83^{b}±3.57	28.81^{c}±2.17	29.70^{b}±3.31	30.22^{a}±3.85	Mean

LSD (day=0.28, day & treatment=0.78, treatment =0.32). T1: control treatment; T2: 2% date palm powder; T3: 4% date palm powder, T4: BHT

Table 4. Effect of using date palm seed powder on sensory properties of frozen beef burgers

Color				
Treatment / Day	T1	T2	T3	mean
0	7.43±0.10	8.52±0.09	8.82±0.13	8.26^{a}±0.64
15	7.03±0.15	8.11±0.18	8.50±0.06	7.88^{b}±0.67
30	7.00±0.10	7.81±0.10	8.16±0.08	7.66^{c}±0.52
mean	7.16^{c}±0.23	8.15^{b}±0.33	8.49^{a}±0.30	
LSD (day=0.15, day & treatment=ns, treatment=0.15)				
Flavor				
Treatment / Day	T1	T2	T3	mean
0	7.06±0.23	7.90±0.07	8.08±0.06	7.68^{a}±0.47
15	6.32±0.05	7.61±0.19	7.83±0.15	7.25^{b}±0.71
30	6.08±0.15	7.08±0.02	7.34±0.01	6.83^{c}±0.57
mean	6.49^{c}±0.57	7.53^{b}±0.37	7.75^{a}±0.33	
LSD (day=0.09, day & treatment=0.15, treatment=0.09)				
Tenderness				
Treatment / Day	T1	T2	T3	mean
0	7.69±0.08	7.83±0.05	7.94±0.05	7.82^{a}±0.12
15	7.35±0.07	7.46±0.10	7.64±0.10	7.48^{b}±0.15
30	7.14±0.02	7.43±0.16	7.44±0.10	7.34^{c}±0.16
mean	7.39^{c}±0.29	7.57^{b}±0.20	7.67^{a}±0.23	
LSD (day=0.08, day & treatment=0.14, treatment=0.08)				
Juiciness				
Treatment / Day	T1	T2	T3	mean
0	7.65±0.05	8.50±0.53	7.94±0.05	8.03^{a}±0.46
15	7.43±0.12	8.43±0.05	8.64±0.10	8.17^{a}±0.56
30	7.15±0.03	8.27±0.04	8.44±0.10	7.41^{b}±0.61
mean	7.41^{b}±0.22	8.40^{a}±0.28	8.34^{a}±0.28	
LSD (day=0.19, day & treatment=0.33, treatment=0.19)				
General acceptance				
Treatment / Day	T1	T2	T3	mean
0	7.40±0.12	8.48±0.05	8.68±0.17	8.19^{a}±0.60
15	7.01±0.01	8.19±0.11	8.51±0.06	7.90^{b}±0.68
30	6.91±0.04	7.84±0.15	8.08±0.06	7.61^{c}±0.54
mean	7.11^{c}±0.23	8.17^{b}±0.29	8.42^{a}±0.28	
LSD (day=0.08, day& treatment=0.54, treatment=0.08)				

extracts, even when used on meat products already held in storage, can improve the quality of the products.

Sensory quality. For this factor, general acceptance scores went up from 7.11 (control, mean across storage) to 8.17 (T2) and 8.42 (T3), about 15–18% higher on the nine-point scale without sensory costs in terms of any of the levels. The results differ from (34), who had the highest concentration of date pit in their tests (6%) being the least acceptable to consumers (close to 4.5 vs. about 5.5 for the control group and lower amounts of DSP) due to lack of juiciness and harder texture. They are also in line with the general tendency indicated by (1), who tested the effect of up to 16% DSP in meatballs that is, in the concentration range where textural consequences of fiber and structure effects are likely to appear. Taken together, this justifies the choice of the 2–4% concentration window for testing the benefits of DSP in this study.

From the results of this study, it is evident that using 2-4% date palm seed powder leads to improvement in all four parameters in a period of 30 days at −18 °C. Treatment T4 (BHT) was excluded from the sensory evaluation in adherence to food safety ethics and to safeguard the health of the panelists from consuming synthetic preservatives. Consequently, the sensory evaluation was limited to treatments T1, T2, and T3.

There are various limitations in this study that need to be highlighted. First, the experiment was carried out on one batch of beef and only one source of beef. There was no consideration of the variation in meat composition. Secondly, the frozen storage time for the experiment was 30 days making it important for future research to consider extended shelf lives. Finally, the effect of packaging variables such as modified atmosphere or vacuum packing was not considered in the experiment.

Conclusion

This study showed that supplementing beef burger meat with date seed powder (*Phoenix dactylifera* L.) significantly improved the quality of beef burgers when frozen. Beef burgers with 2% and 4% date seed powder displayed lower levels of fatty acid degradation and free fatty acids. In addition, there was less microbial development, and the burgers were more palatable than those not treated with date seed powder. In short, date seed powder is effective, has good antimicrobial properties, and functions as an antioxidant.

Ethical Approval: This research has been approved by the Ethics Committee of the College of Agriculture, University of Basrah (Ref. No. 17/37/2026).

Informed Consent: Informed consent was received from all individual panelists before their involvement in the sensory analysis process.

Conflict of Interest: The authors confirm that there is no conflict of interest regarding the research, authorship, and/or publication of this article.

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Data availability: The data used to support the findings of this study are available from the authors upon request.

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