



Enhancing artisanal bread with date-enriched sourdough: texture, shelf life, and perception among algerian consumers

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Abstract

Sourdough bread is valued for its health benefits; however, its adoption in Algeria remains limited. This study aimed to enhance the value of the local date palm (*Phoenix dactylifera*) and improve bread quality by evaluating the impact of date incorporation into the sourdough starter (at 0, 50, 100, and 150 g) on the physicochemical properties (color, texture, porosity) and sensory acceptance of the resulting bread. The results showed that using a date-enriched starter improved the bread's structure. The SB3 sample (150 g of dates) exhibited the highest porosity, giving the crumb an exceptionally airy and light texture. This method also significantly extended the bread's shelf life, particularly in samples SB2 and SB3, thereby reducing food waste. In consumer tests, sample SB2 (100 g of dates) received the highest acceptance rating. This work highlights the potential of sourdough bread made with a date-enriched starter while also identifying challenges for its large-scale adoption in the Algerian market, such as local sensory preferences and economic constraints, for its large-scale adoption.

Keywords Sourdough · Date (*Phoenix dactylifera*) · Bread · Bread storage · Acceptability

1 Introduction

Sourdough bread is widely recognized for its functional benefits and nutritional value, which contribute to improved digestion and the favorable modulation of the gut microbiota (Suo et al. 2021). Its natural fermentation, resulting from the interaction between yeasts and lactic acid bacteria, provides a unique health profile, mainly due to the production of organic acids and probiotics that support digestive

well-being. Despite a resurgence of interest in recent years, sourdough bread remains a niche product compared to the widespread consumption of yeast-leavened bread. This situation can be attributed to several factors, including the technological constraints associated with its fermentation process, which is difficult to scale up industrially (Clement 2018), as well as low consumer demand resulting from a lack of awareness regarding its health benefits. Furthermore, its organoleptic properties, such as its slightly sour taste and firmer crumb texture, can reduce consumer acceptability (Katina et al. 2006). Optimizing the sensory and physicochemical characteristics of sourdough bread therefore remains a major challenge for meeting consumer expectations while ensuring sustainable production practices.

In this context, the incorporation of natural and nutritious ingredients, such as dates (*Phoenix dactylifera* L.), emerges as a promising approach. Dates, the fruit of the date palm, constitute a valuable functional ingredient (Alsarayrah et al. 2023), suitable for the reformulation of cereal-based products due to their remarkable nutritional composition. They are primarily composed of carbohydrates, mainly fructose and glucose, which represent 70–80% of their dry weight, making them an effective natural substitute for sucrose (Al Juhaimi et al. 2020). Their high dietary fiber content contributes to improved digestive health and positively modulates

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the gut microbiota (Al-Habsi 2025). Moreover, dates contain high levels of phenolic compounds (such as phenolic acids, flavonoids) and carotenoids, which provide strong antioxidant activity that exceeds that of many tropical fruits (Harkat et al. 2022). The incorporation of date flour or paste into bakery products has demonstrated several functional advantages, including enhanced moisture retention and extended shelf life (Squeo et al. 2021), improved nutritional value through the addition of fiber and minerals, and a reduction in the glycemic index by replacing refined sugars (Bchir et al. 2022). Dates also contribute to the development of color and aroma through Maillard reactions during baking, thereby enhancing the sensory acceptability of the final products (Shen et al. 2018). The valorization of dates in cereal matrices aligns with current trends focused on developing natural, nutritious, and clean-label products. The addition of dates to sourdough positively influences its technological properties, enhancing the nutritional quality of the bread, its fermentation dynamics, and its textural and organoleptic characteristics. The present study aims to evaluate the impact of incorporating dates into spontaneous sourdough and to examine their effects on the physicochemical and sensory properties of bread, including acidity, specific volume, porosity, and texture. The study also investigates the influence of this formulation on bread shelf life by assessing moisture loss and fungal growth during storage. This research lies at the intersection of technological innovation in baking and the valorization of natural ingredients, contributing to the development of healthy and sustainable alternatives to traditional bakery products.

2 Materials and methods

2.1 Material

Commercial white wheat flour, whole wheat flour, dates (*Phoenix dactylifera* – variety Freza), instant active dry yeast, and salt were procured from a local market in Batna, Algeria.

The Freza variety, a semi-dry date widely cultivated in Algeria, was selected for this study due to its high content of simple sugars (fructose and glucose), which provide an optimal substrate for microbial fermentation, and its significant dietary fiber content, which contributes to moisture retention in the dough. Its local availability and good storability also make it a strategic choice for this research.

The proximate composition of the whole wheat flour used for sourdough preparation was as follows: $12.63 \pm 0.06\%$ moisture, $0.95 \pm 0.12\%$ ash, $12.55 \pm 0.27\%$ protein, and $69.1 \pm 0.09\%$ water absorption. The wheat flour used for bread production had a composition of $12.02 \pm 0.42\%$ moisture, $0.61 \pm 0.11\%$ ash, $12.4 \pm 0.54\%$ protein, and

$61.1 \pm 0.49\%$ water absorption respectively. The composition of date included moisture $22.45 \pm 0.19\%$, ash $1.91 \pm 0.03\%$, soluble solids content $68.9 \pm 0.22^\circ\text{Brix}$, pH $6.44 \pm 0.02\%$, total carbohydrates 67.2% and dietary fiber 6.7%. All analyses were performed in accordance with the official methods of (AOAC, 1990) official methods.

3 Methods

3.1 Preparation of sourdough

Spontaneous sourdough fermentation was carried out following the method described by Minervini et al. (2014), with modifications. The first step in sourdough preparation may involve using only flour and water or incorporating other ingredients naturally rich in microorganisms (inoculum), such as yogurt, rumen cuts, or fruits (Siepmann et al. 2018). In this study, dates were used as a natural inoculum to promote fermentation. The preparation process (Fig. 1) was as follows: dates were soaked in an equal volume of water in a 1:1 ratio for 24 h. The dates were then ground using a laboratory blender. Whole wheat flour and water were added to the mixture in a 1:1 ratio (weight per volume) in a lidded glass jar and left to ferment at 30 °C in an incubator for 24 h. The sourdough was refreshed again every 72 h, several times until the pH stabilized at 4.8 (Różyło et al. 2015).

Four sourdough formulations were prepared with respective levels of date paste proportions of 0 g, 50 g, 100 g, and 150 g, and were designated as TS0 (0 g), TS1 (50 g), TS2 (100 g), and TS3 (150 g), respectively. The sourdough formulations are listed in Table 1. Sourdough preparation was repeated in triplicate. Fermented sourdoughs were used as ingredients for baking (Coda et al. 2011).

3.2 Bread baking

Bread samples were prepared using the basic sourdough bread formula. The amount of flour was considered as 100%, and the other ingredients were measured based on the weight of the flour (Różyło et al. 2015). The formula composition included flour (100%), water (58%), sourdough (20%), and salt (2%). Four bread samples were prepared by successively replacing the sourdough type, as presented in Table 2. These samples were designated as follows: SB0 (prepared with sourdough TS0), SB1 (prepared with TS1), SB2 (prepared with TS2), and SB3 (prepared with TS3). For the control bread, the same formula was used, with sourdough replaced with 2% baker's yeast. This control bread was designated as CB. All the ingredients were placed in a mixer for 2 min at low speed, and 10 min at high speed. The dough was then transferred to bowls, covered with a damp cloth, and then placed to ferment at 28 °C and 80% RH (relative humidity),

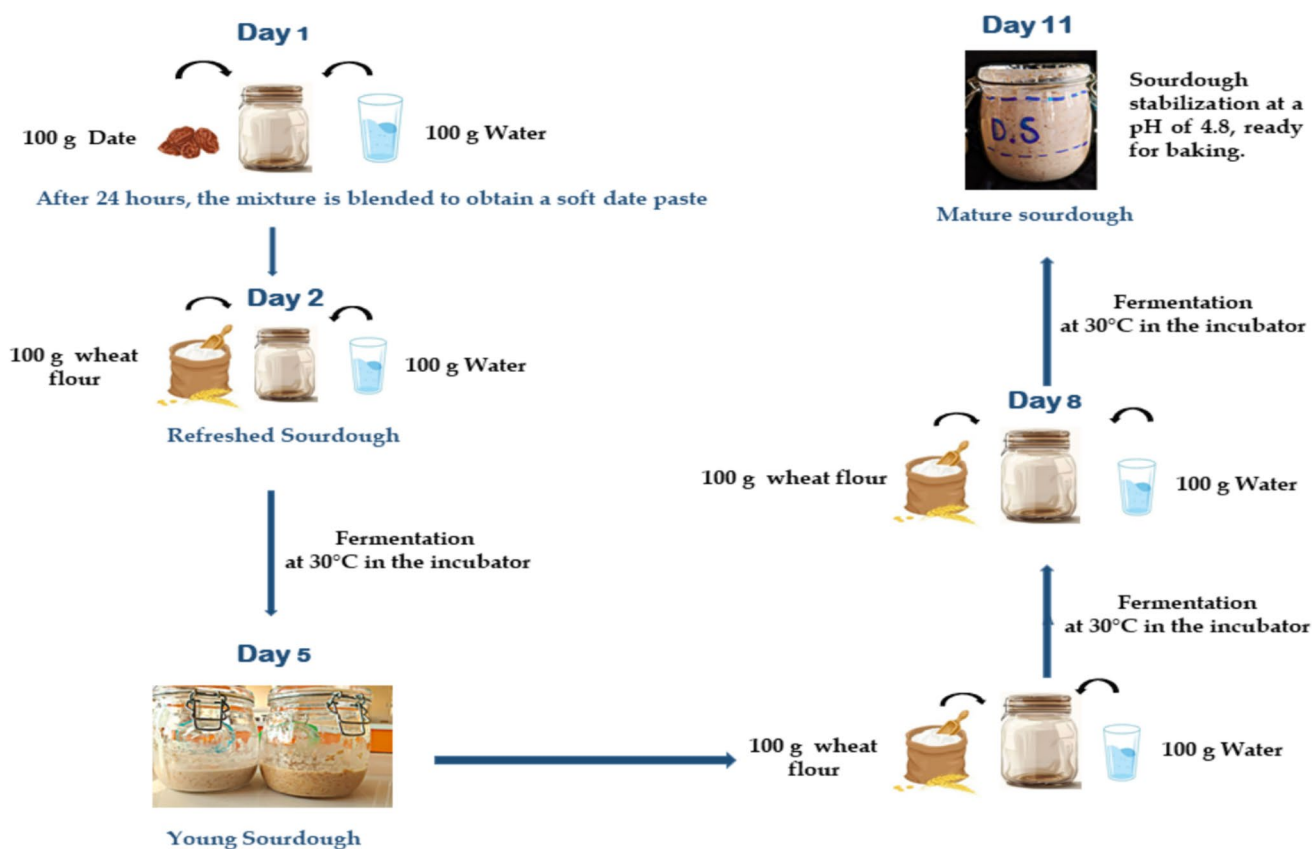


Fig. 1 The process for preparing date sourdough

Table 1 Sourdough formulation samples

Component (g)	TS0	TS1	TS2	TS3
WWF	100	100	100	100
Date paste	0	50	100	150
Water	100	100	100	100

WWF: Whole wheat flour, TS: Traditional sourdough

for 90 min for the first fermentation (Bulk fermentation) in a fermentation chamber. The dough samples were then

weighed and shaped into small baguettes of similar sizes, placed on a bread tray in baking tins, for the second fermentation (proofing fermentation) at 28 °C and 80% RH for 50 min, and baked at 230 °C for 45 min. After baking and cooling, the bread loaves were removed from the tins and subsequently analyzed after 60 min (Olojede et al. 2020). The baking tests were repeated in triplicate.

3.3 Physicochemical analysis

- Acidity properties

Table 2 Bread samples composition

Bread samples	Ingredients %							
	Wheat flour	TS0	TS1	TS2	TS3	water	salt	yeast
SB0	100	20	-	-	-	58	2	-
SB1	100	-	20	-	-	58	2	-
SB2	100	-	-	20	-	58	2	-
SB3	100	-	-	-	20	58	2	-
CB	100	-	-	-	-	58	2	2

The wheat flour (100%) was considered on a flour weight basis, and the other ingredients were calculated in proportion to the weight of the flour. SB: Sourdough bread, TS: Traditional sourdough, CB: Control Bread

The pH of the bread was measured using a pH meter (HACH, France). The bread crumb was mixed with distilled water to obtain a suspension using a 1:1 ratio of bread crumb to distilled water. The mixture was then measured with a suitable electrode. The pH measurements were performed in triplicate (Różyło et al., 2015b).

The titratable acidity (TTA) of the bread was measured by titration with a sodium hydroxide (NaOH) solution. The bread crumb sample was mixed with water, filtered, and titrated with a pH indicator. The acidity was titrated with a 0.1 M NaOH solution (Manshur et al. 2023).

- Bread Yield (BY) and Weight

Bread weight (g) was measured using a precision balance (Radwag, Poland). The bread yield was determined using Eq. 1:

$$BY(\%) = \left(\frac{W_1}{W_2} \times 100 \right) \quad (1)$$

W_1 Bread Weight (g)

W_2 Wheat Flour Weight (g)

- Specific Volume

Bread volume was measured using the rapeseed displacement method (AACC, 2000). The specific volume was measured using the following Eq. (2) (Ngozi, 2014):

$$VS(\text{cm}^3/\text{g}) = V/W \quad (2)$$

VS Specific volume

V Volume (ml)

W Weight (g)

- Porosity

The ImageJ software was used to analyze the internal structure of the bread. A color image of the cross-section was captured to assess the crumb porosity by examining the area fraction (%) and circularity. Digital analysis of the crumb was performed in triplicate (Xie et al. 2023).

- Color

The color properties of the bread (crumb and crust) were analyzed separately. The colorimetric indices for lightness (white-black) (L^*), red-green (a^*), and yellow-blue (b^*) were determined according to the CIELAB color system (Popov-Raljić et al. 2009) using a Chroma Meter (Konica Minolta Sensing, Inc. CR-10, Japan). Crust color was measured at different points on the top of the bread, whereas crumb color was analyzed at the center of each slice. Three measurements were taken for each sample (Olojede et al. 2020).

- Moisture content and loss during storage

The moisture content of the bread samples was monitored over a 10-day storage period to evaluate moisture loss. For each measurement, a 5 g sample (including both crust and crumb) was weighed to obtain its initial mass (W_i). The sample was then dried in a laboratory oven at 105 °C until it reached a constant mass (W_f), according to the standard drying principle (Xie et al. 2023).

The moisture content (MC) was calculated as a percentage using the following Eq. (3):

$$MC(\%) = [W_i - W_f / W_i] \times 100 \quad (3)$$

W_i Initial mass of the fresh bread sample (g)

W_f Constant mass of the dried bread sample (g)

Moisture loss during storage was determined by calculating the difference between the moisture content measured on day 1 (fresh) and that measured on day 10 (end of storage), following the methodology of Alpers et al. (2021). This approach allowed for comparison of moisture retention capacity between the different bread formulations. Throughout the storage period, all bread samples were packaged in sealed plastic bags and maintained at room temperature (24 ± 2 °C), protected from direct light.

- Shelf life

According to the method described by Dal Bello et al. (2007), the shelf life of the bread was evaluated by slicing each loaf aseptically into uniform 25 mm thick slices. Each slice was exposed to air for 5 min on each side, then packed into a heat-sealed plastic bag, leaving a small opening and inserting a transfer pipette to ensure similar aerobic

conditions in each bag. The bags were incubated at room temperature and examined for mold growth over a 9 day storage period. The presence of aerial mycelia (Hager et al. 2012) were used to visually detect fungal growth.

- Sensory evaluation

A consumer sensory evaluation was conducted with 20 untrained evaluators (aged 20–60 years) to assess the acceptability of the bread samples. Using a 9-point hedonic scale where 9 represented 'like extremely' and 1 represented 'dislike extremely', the respondents rated various attributes including appearance, taste, texture, aroma, crust color, crumb color, and overall acceptability (Bolaji et al. 2022a).

3.4 Statistical analysis

Statistical analysis was performed using ANOVA (Analysis of Variance) in the XLSTAT software to compare the samples and determine if significant differences existed between them, with a significance level set at $p < 0.05$. A one-way ANOVA was applied to assess the impact of adding date past to sourdough on the physicochemical properties of the bread.

The statistical analysis of the sensory results was performed as follows: the mean scores for each attribute (appearance, taste, texture, aroma) were first analyzed using a one-way ANOVA. When the ANOVA revealed significant differences ($p < 0.05$), a post-hoc analysis using Tukey's HSD test was conducted identify homogeneous groups among the samples and determine which formulations differed significantly from each other.

4 Results and discussion

4.1 Acidity properties

The analysis of acidity parameters (Table 3) reveals a significant impact of the incorporation of date sourdough. A clear dose–response relationship was observed: increasing the proportion of dates led to a progressive decrease in pH, from 5.34 ± 0.08 (SB1) to 4.87 ± 0.04 (SB3), and a simultaneous increase in Titratable Acidity (TTA), from 3.57 ± 0.01 mL (SB1) to 4.43 ± 0.03 mL (SB3). Statistical analysis confirmed that all samples formed distinct homogeneous groups (letters a-e, $p < 0.05$). Thus, sample SB3 represents the point of maximum acidification. This pronounced acidification is attributed to the addition of dates, a source of fermentable sugars, which stimulates the activity of lactic acid bacteria (LAB) and leads to a higher production of organic acids. The fermentation process involved a combination of yeast and LAB, which metabolize sugars to primarily produce lactic

Table 3 PH and total titrable acidity of Bread Samples

Bread samples	pH	TTA (mL)
SB0	5.81 ± 0.02^a	3.23 ± 0.06^d
SB1	5.34 ± 0.08^b	3.57 ± 0.01^c
SB2	5.16 ± 0.03^c	4.26 ± 0.02^b
SB3	4.87 ± 0.04^d	4.43 ± 0.03^a
CB	5.96 ± 0.014^e	2.92 ± 0.021^e

Different letters in the same column indicate a significant difference ($p < 0.05$)

SB: Sourdough bread, CB: Control Bread

acid, and in the case of heterofermentation, a mixture of lactic acid, acetic acid, ethanol, and CO_2 (Olapade & Adetuyi 2010). Furthermore, the reduction in pH can stimulate proteolytic activity, promoting the release of free amino acids that also contribute to the titratable acidity (Ertop & İbrahim Tuğkan 2018).

The sensory analysis (Figure X) reveals that this controlled acidification directly influenced consumer perception. The moderate acidity in samples SB1 and SB2 corresponded with high taste and acceptability scores, indicating that the balanced sourness enhanced flavor complexity and was preferred by consumers. In contrast, the pronounced acidity of SB3 coincided with a lower taste score, suggesting that the excessive sourness surpassed the optimal acceptability threshold. Therefore, an optimal level of date-induced acidification exists for maximizing consumer preference.

4.2 Physical properties

Analysis of the bread samples' physical properties (Table 4) revealed statistically significant differences ($p < 0.05$) across all measured parameters, establishing clear relationships between formulation and the final structural characteristics of the bread. The incorporation of date sourdough demonstrated a notable effect on structural development, with distinct variations observed in specific volume, porosity, weight, and yield. These parameters, essential for assessing technological quality, are also directly correlated with sensory attributes perceived by consumers. The following discussion examines the impact of each property individually, linking quantitative data to its implications for perceived bread quality.

- Specific Volume

Specific volume, a key parameter for bread lightness, was significantly improved by enrichment with date sourdough. Sample SB3 showed the highest value (2.68 ± 0.014 cm³/g), ranking in the top statistical group (group a), alongside the

Table 4 Physical Properties of Bread Samples

Bread samples	Bread weight (g)	Bread yield (%)	Specific volume (cm ³ /g)	Porosity (%)
SB0	397.95 ± 0.63 ^a	159.10 ± 0.14 ^a	2.32 ± 0.014 ^d	27.647 ± 0.63 ^e
SB1	395.90 ± 0.42 ^b	158.44 ± 0.05 ^b	2.43 ± 0.007 ^c	28.558 ± 0.31 ^d
SB2	392.55 ± 0.21 ^c	156.88 ± 0.11 ^c	2.54 ± 0.00 ^b	30.393 ± 0.20 ^b
SB3	387.25 ± 1.34 ^d	154.86 ± 0.48 ^d	2.68 ± 0.014 ^a	31.40 ± 0.003 ^a
CB	386.36 ± 0.08 ^d	154.54 ± 0.34 ^d	2.61 ± 0.042 ^a	29.308 ± 0.148 ^c

Different letters in the same column indicate a significant difference ($p < 0.05$). SB: Sourdough bread, CB: Control Bread

control CB (2.61 ± 0.042 cm³/g). This performance indicates that the date-sourdough combination achieves leavening efficiency comparable to, or even slightly superior to, that of yeast alone. From a sensory perspective, a high specific volume results in a lighter, less dense bread a visual and tactile attribute strongly associated with superior quality by consumers.

- Porosity

Crumb porosity, which directly reflects aeration, exhibited a clear dose–response relationship with date content. The values increased progressively from 27.65% in the control bread without dates (SB0, group e) to 31.40% in the sample with the highest date content (SB3, group a). All date-enriched breads (SB1 to SB3) demonstrated significantly higher porosity than the conventional bread control (CB, 29.31%, group c). An open, alveolar crumb structure is highly desirable, as it directly influences mouthfeel by providing a soft, airy texture that is generally preferred by consumers over a compact, dense one. The high specific volume and increased porosity observed in SB3 are indicative of a lighter bread, a key quality trait in premium bakery products (Apriliyanti 2020).

- Weight and Yield

The highest bread weight and baking yield were recorded for the control sample without dates, SB0 (397.95 g and 159.10%, respectively, group a), with both parameters decreasing significantly as the date proportion increased. Although a high yield is economically advantageous for producers, the correlated decrease in porosity, as seen in SB0, results in a denser product. In contrast, the lower weight of SB3 (387.25 g, group d) is directly correlated with its exceptional specific volume and porosity. The significantly enhanced porosity and specific volume of SB3 point to a more efficient fermentation process, likely facilitated by the date addition. These results surpass those reported in studies using direct date powder addition (Bolaji et al. 2022b, a). This discrepancy could be explained by the preliminary

hydrolysis of complex compounds during sourdough maturation (Gänzle 2014), which likely enhanced the bioavailability of fermentable substrates from the dates in our preparation, thereby promoting improved gas production and retention. From a consumer standpoint, the light, aerated structure of SB3 is likely perceived as a marker of superior quality compared to the heavier, denser SB0 bread, highlighting a potential trade-off between maximizing production yield and meeting consumer preference for optimal texture.

In conclusion, enriching sourdough with dates significantly improves key physical attributes, notably specific volume and porosity. These structural enhancements, driven by an optimized fermentation process, lead to superior sensory qualities namely, lightness and an airy texture which are major determinants of consumer acceptance and perceived product quality.

4.2.1 Colorimetric characteristics

Colorimetric analysis demonstrated that the incorporation of date sourdough significantly influenced the bread's color (Table 5). A significant darkening was observed, as evidenced by a progressive decrease in L* values (lightness) in both the crust and crumb of the enriched breads (SB1–SB3) compared to the controls (SB0 and CB). Regarding chromaticity, a* values (red–green axis) decreased in the crust of date-enriched breads but remained stable and statistically similar ($p > 0.05$) in the crumb across all samples. Conversely, b* values (yellow–blue axis) increased significantly in the crust, imparting a more yellow hue with higher substitution levels, a trend also reflected as a slight increase in the crumb. This comparative profile highlights a discernible difference between the date sourdough bread and the controls, underscoring the role of date composition in these colorimetric changes.

These chromatic modifications are attributable to the high concentration of fermentable sugars and antioxidant compounds in dates. As reported by Bolaji, 2022a, b), these components promote Maillard and caramelization reaction–during baking, explaining the observed increases in yellow

Table 5 Colorimetric characteristics of bread samples

Bread samples	Crust			Crumb		
	L*	a*	b*	L*	a*	b*
SB0	44.235 ± 0.106 ^a	8.21 ± 0.014 ^b	25.93 ± 0.007 ^b	61.45 ± 0.021 ^a	−0.94 ± 0.014 ^{ab}	16.55 ± 0.042 ^d
SB1	43.28 ± 0.085 ^a	7.25 ± 0.007 ^c	26.24 ± 0.021 ^c	58.65 ± 0.014 ^b	−0.94 ± 0.014 ^{ab}	16.82 ± 0.014 ^c
SB2	41.62 ± 0.014 ^b	7.55 ± 0.007 ^d	27.36 ± 0.007 ^d	53.75 ± 0.021 ^c	−0.96 ± 0.00 ^b	17.28 ± 0.00 ^b
SB3	41.34 ± 0.021 ^b	7.33 ± 0.028 ^e	29.06 ± 0.035 ^e	51.35 ± 0.035 ^d	−0.89 ± 0.028 ^a	17.84 ± 0.035 ^a
CB	44.359 ± 0.08 ^a	8.44 ± 0.01 ^a	24.53 ± 0.11 ^a	61.17 ± 0.06 ^a	−0.92 ± 0.009 ^{ab}	15.58 ± 0.012 ^e

Different letters in the same column indicate a significant difference ($p < 0.05$). SB: Sourdough bread, CB: Control Bread

(b) and red (a) pigmentation, a phenomenon that was most pronounced in the SB3 sample.

The decrease in pH during fermentation further enhances browning reactions, notably by facilitating the Amadori rearrangement. Additionally, studies such as that by Martínez Anaya (1996) have established that fermentation duration is a key factor in the coloration of bakery products, as it influences the formation of brown pigment precursors.

4.3 Moisture loss and shelf life

As illustrated in Fig. 2, moisture loss varied significantly among the five bread samples during the storage period. From the very first day, the control bread (CB) exhibited substantial moisture loss, reaching 10.81%. In comparison, the sourdough breads (SB0, SB1, SB2, and SB3) showed lower moisture losses: 7.34%, 7.01%, 5.99%, and 4.74%, respectively. Sample SB3 demonstrated the best moisture retention throughout the storage period. These results indicate that sourdough bread, owing to its composition and fermentation process, retains moisture more effectively and exhibits better shelf-life potential than yeast-leavened bread.

This observation is supported by Hernández-Figueroa et al. (2023), who reported that the incorporation of sourdough not only enhances flavor but also slows the processes of staling and deterioration. Furthermore, the results indicated that incorporating dates into sourdough significantly improved the dough's water retention capacity. This phenomenon can be attributed to the strong affinity of soluble compounds in dates (notably reducing sugars and dietary fibers) for water molecules, thereby limiting water loss during bread storage (Gull et al. 2015). This hygroscopic property helps to stabilize the crumb structure and delay drying.

As shown in Table 6, significant differences were observed in fungal growth across the five bread formulations. The control sample (CB) developed mold on the third day of storage, whereas a gradual delay in mold onset was noted for the other formulations: SB0 on day 5, SB1 and SB2 on day 6, and SB3 only on day 7. This differential inhibition suggests a dose-dependent antifungal effect associated with sourdough addition. As demonstrated by Alkay et al. (2020), the acidification of the medium by bacterial metabolites (lactic and acetic acids) generated during lactic fermentation is the primary mechanism of action. The correlation between

Fig. 2 Moisture loss (%) during the storage time of bread samples

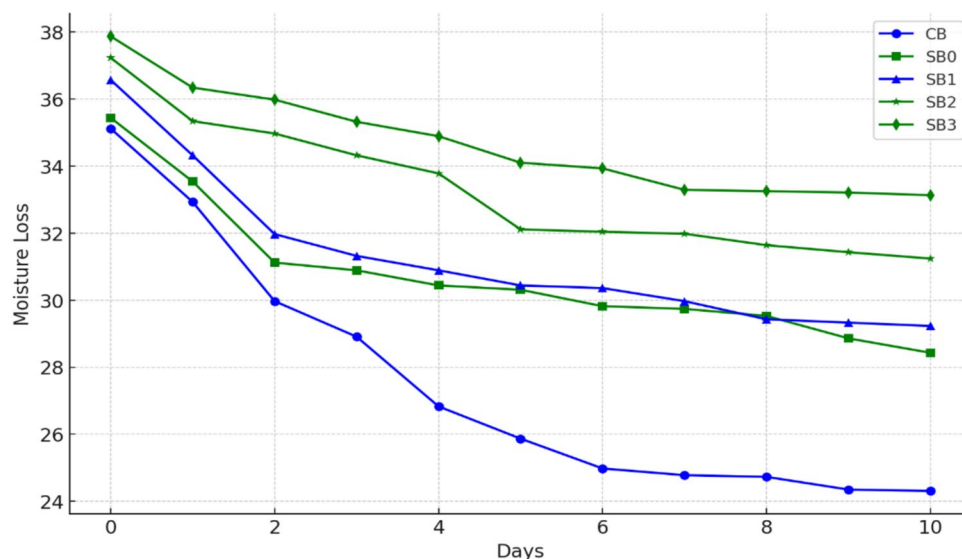


Table 6 Shelf life monitored in days of the bread samples

Bread samples	Days								
	1	2	3	4	5	6	7	8	9
SB0	-	-	-	-	+	+	+	+	+
SB1	-	-	-	-	-	+	+	+	+
SB2	-	-	-	-	-	+	+	+	+
SB3	-	-	-	-	-	-	+	+	+
CB	-	-	+	+	+	+	+	+	+

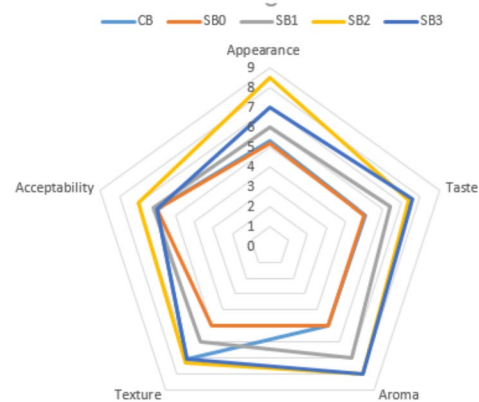
(-): No fungal growth detected visually, (+): Fungal growth detected visually, SB: sourdough bread, CB: control bread

the level of sourdough incorporation and the observed delay in fungal contamination (from SB0 to SB3) confirms this causal relationship, with conventional bread (CB), devoid of sourdough, showing the highest susceptibility.

Overall, the analysis reveals a direct correlation between the bread's physical properties and its shelf life. Sample SB3, which exhibited the most aerated structure (porosity of 31.40%) and the highest specific volume (2.68 cm³/g), also demonstrated the strongest resistance to fungal development. This relationship can be explained by the combined action of several factors: the optimal alveolar structure enables better moisture regulation, while the increased acidity, resulting from enhanced fermentation, creates an environment unfavorable to microbial proliferation. Conversely, sample SB0, with its denser structure (porosity of 27.65%) and less pronounced acidity, showed greater susceptibility to fungal contamination. These results demonstrate that the improvement of physical properties through date-sourdough enrichment significantly contributes to the microbiological stability of the final product. Thus, SB3 is concluded to have the best stability and shelf life. However, this technical performance must be balanced with sensory acceptability, which will be discussed in the following section.

4.4 Sensory properties

Sensory evaluation assessing appearance, taste, texture, aroma, and overall acceptability showed significant differences among the bread samples (Fig. 3). Notably, the SB2 sample emerged as the best-performing overall, achieving the highest acceptability score (7.0/9), largely attributable to its superior appearance (8.5/9) and a well-balanced taste profile (7.4/9). It also presented high scores in aroma (8.0/9) and texture (7.3/9). SB3 followed closely, matching SB2 in aroma (8.0/9) and texture (7.1/9); however, its lower acceptability score (6.0/9) suggests that its specific taste profile

**Fig. 3** The sensory profile of bread samples

(7.6/9) was less preferred by consumers. SB1 received moderate scores, ranging from 6.0–6.4/9 for key attributes, while the control samples CB and SB0 consistently received the lowest ratings, particularly for taste (5.1/9 and 5.0/9, respectively) and aroma (5.0/9 for both).

The results demonstrated a positive correlation between the amount of dates in the sourdough and the improvement in textural parameters, crumb aeration, and visual characteristics of the bread samples. However, this increase also led to a significant increase in acidity, negatively affecting sensory acceptability, particularly when the date content exceeded 100 g in the sourdough formulation.

The observed sensory scores correlate with clear consumer choice patterns, indicating that a balanced flavor profile is valued above technologically optimal texture or shelf-life. The rejection of high-acidity samples, despite their improved technological properties, demonstrates that sensory acceptability can override functional benefits in driving consumer choice. This creates a clear optimization target for product development: maximizing date incorporation for texture improvement while maintaining acidity below the consumer rejection threshold.

5 Conclusion

This study demonstrates that incorporating dates into sourdough is an effective strategy for enhancing the technological and sensory properties of bread. The key finding is the identification of a crucial trade-off: while higher date content (150 g in SB3) maximized improvements in crumb structure, moisture retention, and shelf life, it also elevated acidity beyond consumer acceptance levels. The SB2 formulation (100 g of dates) was established as the optimal compromise, successfully delivering significant quality enhancements while maintaining high consumer preference. This underscores that consumer perception is the ultimate determinant of product success, even when clear technological benefits are present.

The insights from this work provide a foundational understanding of the date-sourdough synergy in bread-making, final product. To fully elucidate the mechanistic basis of these improvements, future research should directly monitor the sourdough fermentation process itself. Tracking key parameters such as pH kinetics, titratable acidity, and CO₂ production dynamics in response to date incorporation will be essential to unravel the fundamental biochemical pathways responsible for the observed enhancements in bread quality. Exploring different date varieties and concentrations will further refine this promising approach for developing nutritious, high quality, and consumer-aligned bakery products.

Author contributions Khalila BELLAL* : Data curation, formal analysis, investigation, software, methodology visualization, writing original-draft Saliha DASSAMIOUR : funding acquisition, project administration, writing-review and editing Mohamed ABDEDDAIM : Conceptualization, resources, supervision, validation.

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Declarations

Competing interests The authors declare that they have no relevant financial or non-financial interests to disclose.

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