Development of sourdough fermented date seed for improving the quality and shelf life of flat bread: study with univariate and multivariate analyses

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Abstract The aim of this work was to study the effects of a novel sourdough system prepared by wheat flour supplemented by combination of pulverized date seed, *Lactobacillus plantarum*, and/or *Lactobacillus brevis* as well as *Saccharomyces cerevisiae* on the sourdough characteristics, quality, sensory, texture, shelf life and image properties of Barbari flat bread. The highest sourdough acidity and bread specific volume was obtained with co-culture of *Lb. plantarum* + *Lb. brevis* + *S. cerevisiae*. The results suggest that fermentation is a potential bioprocessing technology for improving sensory aspects of bread supplemented with pulverized date seed, as a dietary fiber resource. Texture analysis of bread samples during 7 days of storage indicated that the presence of pulverized date seed in sourdough was able to diminish bread staling. The interaction of baker's yeast and lactic acid bacteria (LAB) has led to increase the particle average size of bread crumb and decrease the area fraction than the LAB samples. It was ob-

served that all treatments of sourdough Barbari breads had higher cell wall thickness than the control Barbari bread. Avrami non-linear regression equation was chosen as useful mathematical model to properly study bread hardening kinetics. In addition, principal component analysis (PCA) allowed discriminating among sourdough and bread specialties. Partial least squares regression (PLSR) models were applied to determine the relationships between sensory and instrumental data.

Keywords Barbari bread · Date seed · Sourdough · Staling · Multivariate analysis

Practical application

Date seeds considered a waste product of many date processing plants producing pitted dates, date syrup and date confectionery. The presence of large quantities of fiber and substantial amount of tannins, resistant starch, anabolic agents as well as selenium in date seeds are being recently approved by several investigators, suggest that may have health benefit and it is possible to be evaluated as an excellent source of functional foods components. Fermentation with well-characterized starter cultures—baker's yeast and/or lactic acid bacteria—is a potential means to improve the palatability and processability of fibers and wholemeal flours. Furthermore, fiber fermentation could assist in microflora management and improve the microbiological safety of fiber. The results suggest that fermentation is a potential bioprocessing technology for improving sensory aspects of bread supplemented with pulverized date seed, as a dietary fiber resource.

Research Highlights • A novel sourdough system for dough and Barbari flat bread production was developed.

- The date seed was used as a dietary fiber source in flat bread.
- Principal components analysis (PCA) was used to investigate the sourdough and bread specialties.
- Partial least squares regression (PLSR) models were applied to determine the relationships between sensory and instrumental data.

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Introduction

Date seeds considered a waste product of many date processing plants producing pitted dates, date syrup and date confectionery. Date seeds (pits) comprise 6–12 % of total weight in Tamr stage (completely ripe date fruit), depending on variety and quality grade. Currently, seeds are used mainly for animal feeds in the cattle, sheep, camel and poultry industries. World production of dates reached 7.7 million tonnes in 2010, from this approximately 963 thousand tonnes of date seeds were produced (Habibi Najafi 2011). Chemical composition of date seeds showed high amounts of carbohydrates including dietary fibers (75–80 %), fat (10–12 %) and proteins (5–6 %) (Besbes et al. 2004). Finding a way(s) to make value added products and increase the utilization of date seeds other than pulverized date seeds which are being used traditionally on small scale in animal feed, would be beneficial to both date farmers and processors. The presence of large quantities of fiber and substantial amount of tannins, resistant starch, anabolic agents as well as selenium in date seeds are being recently approved by several investigators, suggest that may have health benefit and it is possible to be evaluated as an excellent source of functional foods components (Habibi Najafi 2011).

Fermentation with well-characterized starter cultures—baker's yeast and/or lactic acid bacteria—is a potential means to improve the palatability and processability of fibers and wholemeal flours (Katina et al. 2006b). Both acidification and activity of enzymes present in grains, especially xylan-degrading enzymes, were shown to contribute to the solubilization of arabinoxylan during the baking process (Hansen et al. 2002). Solubilization of pentosans of flour, and especially transformation of water unextractable arabinoxylan to water extractable arabinoxylan, has been reported to improve bread volume and texture in wheat baking (Courtin and Delcour 2002) and in high-fiber wheat baking (Katina et al. 2006b). In wheat sourdough baking, the influence of commercial pentosanases on the molecular weight of arabinoxylans was shown to be dependent on the starter type (Devesa and Martlnez-Anaya 2001).

Flat breads are the main dietary staple in many Middle Eastern and North African countries (Pourfarzad et al. 2011). Few works on study the supplementation of bread with a pulverized date seed have been published. Bouaziz et al. (2010) investigated the effect of defatted date seeds on wheat dough performance and bread quality. Heated defatted Agwa and Aprimi seeds, added at levels of 1 and 3 %, enhanced bread quality and shelf life (Wasif 1996). Almana and Mahmoud (1994) showed that the coarse fraction of date seed affected the mixing characteristics and extensography parameters in a relatively similar manner to wheat bran, but the fine fraction behaved in a different manner, causing deterioration in bread color, flavor, odor, chewing, uniformity and overall

acceptability. Hejri-Zarifi et al. (2013), examined the two fractions: germ and residue of milled germinated palm date seeds. Although improvement in dough rheology was monitored but specific volume of bread was not affected by both fractions.

Thus, the present study was designed: (a) to examine the effects of a novel sourdough system prepared by wheat flour supplemented by combination of pulverized date seed and different types of fermentation (yeast fermentation, heterofermentative and homofermentative lactic acid fermentation, combined and spontaneous fermentation) on quality, shelf life, image and sensory aspects of flat bread; and (b) to obtain the relationship between bread parameters by using multivariate mathematical-statistical methods such as partial least squares regression analysis (PLSR) and principal components analyses (PCA) as ways to propose simple procedures to quantify texture that could have an effect on bread shelf life.

Materials and methods

Materials

Commercial *Triticum aestivum* wheat flour (locally named Setareh) was procured from the AceeArd Co., Khorasan, Iran. Dried active baker's yeast was obtained from Razavi Co., Khorasan, Iran. An important commercial variety of date fruits, namely Kabkab (*Phoenix dactylifera* (L.), var. Kabkab), used in this study were collected in the Fars area in Iran. The seeds were removed from the fruits, soaked in water, washed to free them from any adhering date flesh and dry milled to powdered form (100 mesh).

Methods

Chemical and physical analysis of flour and date seeds

Moisture (44–16 A), protein (46–13), ash (08–07), fat (30–10), wet gluten (38–11), falling number (56–81) and crude fiber (32–10.01) were determined according to standard AACC methods (2000). Carbohydrate content was estimated by difference of all compounds from 100.

Sourdough fermentation

Sourdough fermentation was obtained by using two different starters selected on the basis of homo/hetero fermentative property. These LAB strains were previously isolated from traditional Iranian raw milk cheese and characterized by polyphasic approach (Edalatian et al. 2012).

Eight different batches of fermentation were applied to the mixture of wheat flour and pulverized date seed: 1) A: *Lb. plantarum* (homofermentative), 2) B: *Lb. brevis* (heterofermentative), 3) C: *S. cerevisiae*, 4) A + B, 5) A +

C, 6) B + C, 7) A + B + C, 8) Spontaneous fermentation (no starter added). The sourdoughs were prepared by mixing Two hundred grams of pulverized date seed, 195 ml of tap water and 5 ml of the cell suspension, containing each lactic acid bacterium to achieve viable counts of about 10^7 cfu/g, to produce 400 g dough (dough yield of 200) with a continuous high-speed mixer (60× g; dough mixing time, 5 min).

To obtain yeast fermentation, 200 g of pulverized date seed was mixed carefully with 200 ml of tap water, and with 7.5 g of fresh baker's yeast (10^6 cfu/g). Spontaneous fermentation occurred after mixing tap water and pulverized date seed in a beaker. All mixtures were covered with aluminum foil and fermented for 24 h at 30 °C (Katina et al. 2007).

pH and TTA

The pH value was measured from an aliquot of 10 g of sourdough blended with 100 mL distilled water. For the determination of TTA, this suspension was titrated against 0.1 M NaOH to a final pH value of 8.5. TTA was expressed as the amount of NaOH used (mL) (Nollet 2004; Paramithiotis et al. 2006).

Bread making and evaluation

The bread investigated in this study was “Barbari”, which is one of the most popular flat breads in Iran. This bread was produced using a standard method described by Pourfarzad et al. (2011). Raw fiber of date seed (unfermented) was used at level of 10 g/100 g wheat flour in the raw fiber reference bread according to the literature reports and economic aspects. Prepared sourdoughs were used at the level of 20 g/100 g of bread dough. After cooling, bread samples were packed in polyethylene bags, stored at room temperature and evaluated. Quality analysis of fresh bread samples was carried out by measuring specific volume of the central slice (rapeseed displacement) (Pourfarzad et al. 2013).

Sensory evaluation

Sensory analysis was carried out using a 5-point ranking scale with scores ranging from 1 (least pleasure) to 5 (best pleasure). Sensory evaluation was performed by 10 trained panelists. Attributes of bread were selected according to the Iranian flat bread evaluation method, including bread form and shape; upper and bottom surface properties; cavity and porosity; firmness and softness of texture; chewing ability; odor, flavor and taste and overall quality score (Rajabzadeh 1991). For each of the attributes, the average of the panelist scores was calculated.

Texture analysis

Staling phenomenon and its changes were evaluated by penetration test. A texture analyzer (model QTS 25 kg, CNS Farnell, Hertfordshire, UK) was used to measure the hardness according to Pourfarzad et al. (2011) at 2, 24, 48 h and 5 day after baking. Values for the Avrami model factors were estimated by fitting experimental points into the non-linear regression equation (Armero and Collar 1998):

$$\theta = \frac{H_{\infty} - H_t}{H_{\infty} - H_0} = e^{-kt^n} \quad (1)$$

where θ is the fraction of the recrystallization still to occur, H_0 is the bread hardness at zero time, H_{∞} is the bread hardness at ∞ time, H_t is the bread hardness at t time, k is a rate constant (usually used $1/k$ = time constant to compare bread hardening rate), and n is the Avrami exponent. Regression was done by using the Curve Expert 1.3 software (Starkville, MS, USA).

Image analysis

For each bread loaf, three slices were obtained from the central region and images were captured using flatbed HP Scanjet G4010 Photo Scanner (Hewlett-Packard, Palo-Alto, CA, USA) supporting Desk Scan II software (Hewlett Packard, USA). The CIE $L^*a^*b^*$ (or CIELAB) color model was used for determination of the crust color parameters i.e. lightness (L^*), redness (a^*), blueness (b^*) and total color difference (ΔE). The selected crumb grain features were the average size, area fraction, solidity and circularity, fractal dimension and cell wall thickness, which, calculated according to the method proposed by Pourfarzad and Habibi-Najafi (2012).

Statistical analyses

In order to assess significant differences among samples, a completely randomized design was performed. Duncan's new multiple range test was used to describe means with 95 % confidence. PCA and PLSR were performed on mean sourdough, baking and sensory data sets. All statistical analyses were carried out using Minitab 16 software (Minitab Inc., State College, PA, USA). Results were reported as the average of three replications (all treatments were evaluated in three batches).

Results and discussion

Physicochemical characteristics of wheat flour and pulverized date seed

The Physicochemical compositions of wheat and pulverized date seeds are presented in Table 1. The characteristics of the

Table 1 Quality characteristics of wheat and date seed flours^a

Attribute	Wheat flour	Date seed flour
Moisture (g/100 g flour)	10.52 ± 0.36	6.52 ± 0.21
Protein (g/100 g, w.b.)	10.82 ± 0.24	5.51 ± 0.25
Fat (g/100 g, w.b.)	1.76 ± 0.51	9.61 ± 0.54
Ash (g/100 g, w.b.)	0.79 ± 0.01	1.11 ± 0.16
Carbohydrates (g/100 g, w.b.)	76.13 ± 1.12	77.32 ± 1.16
Wet gluten (g/100 g)	26.71 ± 0.55	–
Extraction rate (g/100 g)	82.01 ± 1.51	–
Falling number (s)	407.02 ± 3.01	–
Total dietary fiber (g/100 g)	–	22.11 ± 0.51

^a Mean of three measurements ± standard deviation

flour are in the range of typical values of medium strong flour, suitable for Iranian Barbari flat bread. Date seed has noticeable amounts of protein and fat; however the content of total ash is low. Pulverized date seed has also high content of fiber; accordingly it can be considered an important source of dietary fiber to be used for enrichment of flat breads (Habibi Najafi 2011).

Acidity development in sourdoughs

The acidity level of all sourdough samples varied within pH 4.06–5.92 and TTA 0.208–0.905 in the experimental region (Fig. 1). Acidity development was dependent on the strain and fermentation conditions. The most acidic sourdough was obtained with *Lb. brevis* + *Lb. plantarum* + *S. cerevisiae* (A + B + C) and the least acidic sourdough was obtained with spontaneous fermentation. The sourdoughs produced with heterofermentative LAB (*Lb. brevis*) had the lowest pH and highest titratable acidity than the homofermentative LAB (*Lb. plantarum*). The pH of the sourdough was 5.85 in yeast fermentation. However, the most acidic sourdough (pH ≤ 4.62) was obtained when pulverized date

seed was fermented by combination of baker's yeast and lactic acid bacteria. Compatibility of associations between lactic acid bacteria and baker's yeast and their effects on acidity is widely documented (Paramithiotis et al. 2006). The acidity of sourdough made with mixture of baker's yeast with lactic acid bacteria was significantly higher than the baker's yeast and LAB, individually. This might be due to the fact that lactic acid bacteria increase metabolic activity of baker's yeast (Gobbetti et al. 1995). Similar results were observed in Italian (Corsetti et al. 1998) and Greek (Paramithiotis et al. 2006) sourdoughs.

Specific volume

Volume of bread samples is a quality parameter as it indicates dough inflating ability and oven spring. As it can be seen in Fig. 2, the specific volume of all bread samples varied from 2.13 to 4.65 cm³/g. The highest specific volume was obtained with co-culture of *Lb. plantarum* + *Lb. brevis* + *S. cerevisiae* (A + B + C) and the lowest specific volume was obtained with bread supplemented with raw fiber. Volumes of sourdough breads produced with LAB (especially *Lb. brevis*) were higher than bread produced with *S. cerevisiae* alone. The highest volumes (3.80–4.65 cm³/g) were obtained when heterofermentative strain (*Lb. brevis*) was individually associated with *S. cerevisiae*. The four bread samples in the highest volume group were among most high acidity. The application of sourdough has been reported to either improve (Crowley et al. 2002) or decrease bread volume (Barber et al. 1992); type of influence being dependent on the acidification rate obtained and on the microbial strains utilized. Positive influence of sourdough on volume might be due to various factors: (1) heterofermentative lactic acid bacteria have been reported to increase metabolic activity of baker's yeast (Gobbetti et al. 1995) and thus produce more carbon dioxide for leavening; (2) appropriate acidity might enhance the ability of gluten to

Fig. 1 pH and TTA values of sourdoughs made with date seed flour; TTA, total titratable acidity of sourdough; Each observation is a mean ± SD of three replicate experiments ($n = 3$); Values in columns with different letters are significantly different ($p \leq 0.05$)

Fig. 2 Specific volume of sourdoughs made with date seed flour; Each observation is a mean $\pm$ SD of three replicate experiments ($n = 3$); Values in columns with different letters are significantly different ($p \leq 0.05$)

retain CO₂ (Gobbetti et al. 1995) (3) accumulation of water soluble pentosans may increase volume as a result of altered water distribution (Corsetti et al. 1998). According to our results, utilization of fermented pulverized date seed improves protein network (enhanced CO₂ retention).

Sensory attributes

The effects of addition of date seed fractions on the sensory parameters are shown in Table 2. Results showed no significant difference for the visual appearance (form and shape, upper and bottom surface properties) among the samples. The porosity and firmness scores in sensory analysis of bread samples were increased with addition of sourdough. Chewing ability is another important attribute for flat bread quality. The results perceived by the trained panelists showed no significant difference in chewing ability between the control and bread samples containing sourdough. This might be due to the diminishing the negative effects of crude fiber of date seed on the mouth feel. Odor and flavor are two main important taste characteristics in food acceptance. As it is difficult to determine a taste profile by instrumental measurements, an investigation of the impact of fermentation of pulverized date seed on Barbari bread taste profile by sensory evaluation is necessary. It can be seen in Table 2, all sourdough treatments caused significantly increase the taste score and the effect of sourdough made with B + C and A + B + C was greater than other treatments. This might be due to the synergistic effect of lactic acid bacteria and yeast and subsequently production of special aroma (Gobbetti et al. 1995). Proteolysis during fermentation provides precursor compounds for the formation of aroma volatiles during baking as well as substrates for microbial conversion of amino acids to flavor precursor compounds

(Thiele et al. 2002). Thus, the use of sourdough in wheat breads has gained popularity in recent times as a means to improve the quality and flavor of breads. It can be concluded that fermentation of pulverized date seed do not have any significant effect on the sensory properties of fresh bread samples than the control, except for co-culture of B + C, which improves scores for overall quality of fresh Barbari bread. Thus, it appears that sourdough fermented date seed, as a dietary fiber resource, may be successfully incorporated into bread without negatively impacting texture and overall acceptability. Robert et al. (2006) and Katina et al. (2006a) reported relatively similar results in sourdough production.

Texture analysis

Crumb texture is critical to consumer acceptance of baked products. The kinetic of bread hardening was modeled using the Avrami equation as reported previously for describing crystallization kinetics during storage (Armero and Collar 1998). This equation has been used for explaining bread staling based on starch retrogradation, despite the contribution of the other bread components (Armero and Collar 1996). Kinetic parameters obtained from the fitted curves are shown in Table 3. The resulting adjusted models provided information on the hardness of fresh breads and on the hardening kinetics. Initial hardness (H_0) of fresh breads could be accurately estimated and varied widely from 13.47 to 153.65 N reflecting a close dependence on the type of produced sourdough. The Avrami kinetic parameters – limiting modulus (H_∞), rate constant (k), and Avrami exponent (n) – defined the shape of the firming curve along bread storage. Extreme values from the accurate estimation of limiting modulus were from 30.81 to 228.50 N. Bread hardening kinetics strongly depended on

Table 2 Sensory characteristics of fresh Barbari bread containing sourdoughs of date seed flour

Treatments	Form and shape	Upper surface properties	Bottom surface properties	Cavity and porosity	Firmness and softness of texture	Chewing ability	Odor, flavor and taste	Overall quality score
Control	3.90 ^a	4.30 ^a	3.20 ^a	3.10 ^e	2.90 ^c	3.40 ^{ab}	2.90 ^{bc}	3.48 ^{bcd}
Row fiber	3.50 ^a	3.70 ^a	3.60 ^a	3.20 ^{de}	3.00 ^c	2.30 ^b	2.60 ^c	3.07 ^d
<i>Lb. plantarum</i> = A	3.90 ^a	4.10 ^a	3.40 ^a	3.90 ^{abcde}	3.40 ^{bc}	3.70 ^a	3.60 ^{abc}	3.75 ^{abcd}
<i>Lb. brevis</i> = B	4.10 ^a	4.00 ^a	3.80 ^a	3.50 ^{bcde}	3.40 ^{bc}	3.50 ^a	3.90 ^{abc}	3.78 ^{abc}
<i>S. cerevisiae</i> = C	4.00 ^a	4.00 ^a	4.00 ^a	4.30 ^{abc}	4.00 ^{abc}	4.10 ^a	3.90 ^{abc}	3.99 ^{ab}
A + B	3.90 ^a	3.90 ^a	3.50 ^a	3.80 ^{abcde}	3.60 ^{abc}	3.50 ^a	3.60 ^{abc}	3.71 ^{abcd}
A + C	3.90 ^a	4.00 ^a	3.40 ^a	4.20 ^{abcd}	4.20 ^{ab}	4.30 ^a	3.80 ^{abc}	4.01 ^{ab}
B + C	4.10 ^a	4.20 ^a	3.70 ^a	4.80 ^a	4.70 ^a	4.50 ^a	4.30 ^a	4.35 ^a
A + B + C	3.90 ^a	4.00 ^a	3.60 ^a	4.40 ^{ab}	4.70 ^a	4.40 ^a	4.00 ^{ab}	4.15 ^{ab}
Spontaneous	3.50 ^a	3.80 ^a	3.80 ^a	3.30 ^{cde}	3.00 ^c	3.40 ^{ab}	2.60 ^c	3.29 ^{cd}
SEM ($\pm$)	(0.208)	(0.192)	(0.193)	(0.218)	(0.236)	(0.234)	(0.278)	(0.145)

Each observation is a mean of three replicate experiments ($n=3$)

SEM, standard error of the mean

Values in columns with different letters are significantly different ($P \leq 0.05$)

both k and n . High k or n values led to fast crumb firming kinetics; on the contrary, breads with low n and/or k and/or H_∞ values were those with especially slow crumb firming kinetics. Breads containing sourdough showed the lower constant k than the control and raw fiber samples, indicating slower rate for development of hardening during storage, related to the rate of crystals growing (Torre et al. 1995). Also, concerning the Avrami exponent n , results indicated that all fermentation treatments of pulverized date seed caused a reduction in this parameter, which has been related to the type of crystal

nucleation and their growing geometry (Torre et al. 1995). It can be observed that addition of all sourdough treatments resulted in similar texture as fresh control. While, breads containing raw fiber has the most hardness among bread samples. Hardening kinetics of bread samples supplemented with fiber sourdough was slower than kinetics of unsupplemented breads (control and raw fiber samples) over 7 days of storage. Also, the samples of B + C and A + B + C had the softer texture after 7 days. The increase of hardness during storage has been attributed mainly to amylopectin recrystallization, although other phenomena, such as moisture diffusion between crumb and crust, and the starch–gluten interactions, has been proposed to additional players that contribute to hardness increment (Zobel and Kulp 1996). The fibrous sourdough added has the ability to interact with water, therefore limiting the water available for starch gelatinization/recrystallization and most likely modifying the structure of the crystals produced, as has been previously observed for some fibers (Peng et al. 2010). In fact, flour replacement at different levels by dietary fibers from different sources significantly modifies the qualitative and quantitative thermal profile on starch gelatinization and amylopectin retrogradation and kinetics during storage in different extend depending on the fiber source (Santos et al. 2008). On the other hand, several studies provide evidence that exo-polysaccharides produced by sourdough LAB have the potential to improve bread texture and shelf life (Arendt et al. 2007). Starch molecules can be affected by enzymes produced by LAB, causing a variation in the retrogradation properties of the starch, which slows the rate of staling (Corsetti et al. 1998). Additionally, the acidic conditions and proteases associated with sourdough play a role in reducing the staling rate of bread (Arendt et al. 2007).

Table 3 Staling kinetic parameters during storage of breads containing sourdoughs of date seed flour obtained from the adjusted mechanical characteristic of hardness fitted to the Avrami equation

Treatments	H_0 (g force)	H_∞ (g force)	k	n	R^2
Control	60.97 ^b	217.13 ^a	0.26 ^a	4.30 ^a	0.993
Row fiber	153.65 ^a	228.50 ^a	0.34 ^a	4.46 ^a	0.946
<i>Lb. plantarum</i> = A	46.01 ^b	177.51 ^b	0.03 ^b	1.58 ^b	0.999
<i>Lb. brevis</i> = B	50.78 ^b	122.81 ^c	0.05 ^b	1.77 ^b	0.882
<i>S. cerevisiae</i> = C	22.42 ^b	113.84 ^c	0.07 ^b	1.20 ^b	0.975
A + B	43.79 ^b	101.32 ^{cd}	0.01 ^b	1.73 ^b	0.935
A + C	36.71 ^b	71.13 ^{de}	0.02 ^b	1.50 ^b	0.915
B + C	13.47 ^b	30.81 ^f	0.01 ^b	1.14 ^b	0.092
A + B + C	23.88 ^b	39.26 ^{ef}	0.02 ^b	1.37 ^b	0.958
Spontaneous	58.72 ^b	120.96 ^c	0.08 ^b	2.52 ^b	0.879
SEM ($\pm$)	(7.465)	(4.814)	(0.027)	(0.261)	–

Each observation is a mean of three replicate experiments ($n=3$); Values in columns with different letters are significantly different ($P \leq 0.05$); SEM, standard error of the mean; H_0 is the bread hardness at zero time, H_∞ is the bread hardness at ∞ time, k is a rate constant and n is the Avrami exponent

Image properties

The surface color of bread is an important quality feature, associated with aroma, texture, and appearance characteristics. In fact, color is an essential attribute of bread, contributing to consumer preference (Pourfarzad et al. 2014). Digital image analysis was used to characterize crust and crumb structure and compare the breads (Table 4). The crust lightness (L^*) was increased by the application of sourdough in all sourdough formulations than the raw fiber sample and these differences were not significant with the control bread. The color change of crust under sourdough fermentation might be related to the fact that sugars participated in caramelization during baking. Also, phenolic compounds of date seed fiber underwent over bleaching reaction. The color change mechanism in colored plant materials due to interaction with a bleaching agent such as lactic acid produced during sourdough fermentation is not yet completely clear. However, two possible mechanisms have been suggested to explain the bleaching mechanism: (1) the bleaching mechanism was explained by the oxidation of surface pigments. These pigments are generally quinones resulted from the oxidation of phenolic compounds. (2) The second bleaching mechanism is the oxidation of amine compounds of proteins, which are bond to phenolics (Pourfarzad et al. 2013). The a^* and b^* values of bread samples were increased by sourdough fermentation than the raw fiber sample. The maximum value of redness was recorded by B + C sample which was similar to control bread. On the other hand, the values of yellowness were not different between all sourdough formulations, although they were lower than control sample. It is believed that low pH circumstance

created by bacterial activities and hydrolysis of long chain molecules can contribute to accelerate the Maillard reaction which lead to change in the redness and yellowness values (Esteller et al. 2006).

Visual characteristics of crumb such as average size, area fraction, cell wall thickness, solidity, circularity and fractal dimension are elements of the quality of the final product. According to Table 4, fermentation with baker's yeast starters led to the highest average size and area fraction in the crumb of Barbari bread. Heterofermentative lactobacilli produced smaller and higher cells than the homofermentative strain which resulted in the lower average size but higher area fraction of *Lb. brevis* than the *Lb. plantarum*. Also, interaction of baker's yeast and LAB led to an increase in the average size, but decreased the area fraction compare to LAB samples. It was observed that all sourdough breads had higher cell wall thickness than the control Barbari bread. Also, breads containing raw fiber showed thicker cell walls than the control sample which was claimed by other related studies (Angioloni and Collar 2011). Furthermore, sourdough containing lactic acid bacteria especially *Lb. brevis* had higher cell wall thickness than the baker's yeast sourdough. This might be due to the higher acidity production. Thus, combination of baker's yeast and LAB in sourdough formulation resulted in increasing the cell wall thickness. In addition, there was no significant change in solidity (0.82–0.92), circularity (0.69–0.84) and fractal dimension (1.86–1.88 mm).

Relationships between quality, shelf life, sensory and image parameters in Barbari bread

Correlation coefficients between various characteristics of sourdough and breads are given in Table 5. It is evident from the data that most of evaluated characteristics had

Table 4 Image characteristics of fresh Barbari bread containing sourdoughs of date seed flour

Treatments	L^*	a^*	b^*	Average size	Area fraction	Fractal dimension	Cell wall thickness	Circularity	Solidity
Control	46.60 ^a	25.57 ^a	23.98 ^a	3.07 ^f	31.88 ^f	1.88 ^a	0.05 ^g	0.84 ^a	0.92 ^a
Row fiber	40.18 ^b	17.10 ^d	13.56 ^c	1.94 ^g	20.16 ^g	1.88 ^a	0.24 ^a	0.82 ^a	0.89 ^a
<i>Lb. plantarum</i> = A	45.90 ^a	22.28 ^b	19.63 ^b	4.06 ^c	35.89 ^{ef}	1.88 ^a	0.10 ^c	0.75 ^a	0.87 ^a
<i>Lb. brevis</i> = B	46.18 ^a	21.41 ^b	18.28 ^b	3.45 ^{ef}	42.24 ^c	1.88 ^a	0.12 ^d	0.72 ^a	0.86 ^a
<i>S. cerevisiae</i> = C	45.63 ^a	18.64 ^c	17.78 ^b	7.79 ^a	80.94 ^a	1.88 ^a	0.07 ^f	0.69 ^a	0.82 ^a
A + B	46.29 ^a	18.62 ^c	17.65 ^b	4.88 ^d	50.72 ^d	1.88 ^a	0.14 ^c	0.80 ^a	0.87 ^a
A + C	45.82 ^a	21.80 ^b	18.01 ^b	6.25 ^c	64.95 ^c	1.87 ^a	0.13 ^{cd}	0.84 ^a	0.87 ^a
B + C	49.33 ^a	24.32 ^a	19.38 ^b	5.82 ^c	60.48 ^c	1.87 ^a	0.14 ^c	0.78 ^a	0.87 ^a
A + B + C	45.57 ^a	19.29 ^c	17.78 ^b	6.98 ^b	72.60 ^b	1.88 ^a	0.22 ^b	0.84 ^a	0.89 ^a
Spontaneous	46.06 ^a	19.44 ^c	18.07 ^b	3.09 ^f	32.08 ^f	1.88 ^a	0.05 ^g	0.80 ^a	0.88 ^a
SEM ($\pm$)	(0.704)	(0.191)	(0.560)	(0.101)	(1.051)	(0.002)	(0.002)	(0.037)	(0.019)

Each observation is a mean of three replicate experiments ($n=3$); SEM, standard error of the mean; Values in columns with different letters are significantly different ($P \leq 0.05$)

Table 5 Pearson's correlation matrix between values of quality, shelf life, sensory and image characteristics of Barbari bread containing sourdough of date seed flour

	S.V.	H_1	H_3	H_5	H_7	L^*	a^*	b^*	k	n	Fractal	CWT	Average size
H_1	-0.742*												
H_3	-0.857**	0.919***											
H_5	-0.89**	0.798**	0.938***										
H_7	-0.936***	0.762*	0.92***	0.974***									
L^*		-0.872**	-0.817**										
a^*						0.673*							
b^*						0.679*	0.864**						
k	-0.725*	0.847**	0.906***	0.908***	0.823**	-0.684*							
n	-0.728*	0.831**	0.858**	0.918***	0.826**				0.957***				
Fractal								-0.701*					
CWT													
Average size	0.811**	-0.77**	-0.704*	-0.768**	-0.749*				-0.659*	-0.776**			
Area fraction	0.829**	-0.766*	-0.711*	-0.778**	-0.778**				-0.653*	-0.771**			0.989***
Circularity													
Solidity										0.704*			
pH	-0.891**	0.644*	0.811**	0.845**	0.845**				0.801**	0.736*			
Acidity	0.888**		-0.728*	-0.774**	-0.783**				-0.676*	-0.658*			
Form		-0.73*				0.68*							
USP						0.714**	0.904***	0.885**					
BSP													
Cavity	0.83**	-0.724*	-0.761*	-0.854**	-0.828**				-0.711*	-0.824**	-0.761*		0.864**
Odor	0.922***	-0.679*	-0.764*	-0.858**	-0.881**				-0.654*	-0.752*	-0.737*		0.853**
Chewing	0.846**	-0.933***	-0.891**	-0.84**	-0.841**	0.755*			-0.788**	-0.818**	-0.677*		0.856**
Softness	0.778**	-0.774**	-0.75*	-0.792**	-0.758*				-0.762*	-0.853**			0.774**
Overall quality	0.86**	-0.861**	-0.837**	-0.837**	-0.831**	0.69*			-0.76*	-0.833**	-0.709*		0.844**
Circularity													
Solidity		0.819**											
pH													
Acidity	0.634*			-0.925***									
Form													
USP						0.716*							
BSP		-0.682*	-0.716*										
Cavity	0.839**			-0.705*	0.697*								
Odor	0.853**			-0.774**	0.817**				0.957***				

Table 5 (continued)

	S.V.	H_1	H_3	H_5	H_7	L^*	a^*	b^*	k	n	Fractal	CWT	Average size
Chewing	0.845**			-0.684*	0.676*	0.677*			0.864**	0.856**			
Softness	0.791**			-0.764*	0.738*	0.875**			0.87**	0.852**	0.823**		
Overall quality	0.847**			-0.757*	0.746*	0.811**			0.927***	0.921***	0.942***	0.954***	

p -values below 0.05 (*), 0.01 (**) and 0.001 (***) indicate statistically significant non-zero correlations at the 95%, 99% and 99.9% confidence level, respectively; SV: Specific volume; H_i is the bread hardness at t time; k is a rate constant and n is the Avrami exponent; Fractal: fractal dimension; CWT: Cell wall thickness; Form: form and shape; USP: Upper surface properties; BSP: Bottom surface properties; Cavity: cavity and porosity; Odor: odor, flavor and taste; Chewing: chewing ability; Softness: softness and firmness of texture

interrelationship. Specific volume, which is one of the important quality parameters, was negatively and significantly correlated to bread hardness during 7 days after production, Avrami kinetic parameters (n and k) and pH of sourdough but positively correlated to average size, area fraction, acidity of sourdough and sensory parameters i.e. cavity and porosity, odor, flavor and taste, chewing ability, firmness and softness of texture and overall quality score. Lightness of bread as an image parameter was found to be positively correlated to redness, blueness, form and shape, upper surface properties, chewing ability and overall quality score but negatively correlated to hardness during 3 days after production and constant rate of Avrami kinetic (k). It is clear from the data that among image characteristics of bread crumb, area fraction and solidity had the most and least significant correlations with bread and sourdough characteristics, respectively. The results also confirmed that pH and acidity of sourdough exhibited highly significant correlations with different parameters of bread which could help us to analyzing behavior of them. As it was clear from Table 5, shelf life and staling properties of bread had significant correlation with quality and image properties which could be used for prediction and shelf life testing studies. On the other hand, the high significant correlations between sensory characteristics and other bread and sourdough properties could be used for prediction of sensory aspects of final product via quality and image properties.

Principal Component Analysis (PCA)

Data on sourdough acidity, quality, shelf life, image and sensory aspects of flat bread were subjected to PCA (Fig. 3). The multivariate treatment of the data obtained for the samples permitted the reduction of the variables to two principal components, which together explained 74.8 % of the total variability. The first axis accounted for 57.5 % and the second axis for 17.3 %. According to the PCA biplot, hardness during 7 days storage, staling kinetic parameters, fractal dimension, cell wall thickness, circularity, solidity and pH of sourdough were negatively correlated to PC1 axis whereas other bread and sourdough characteristics were positively correlated to PC1 axis. Specific volume, hardness during 3 days storage, fractal dimension, cell wall thickness, average size, area fraction, sourdough acidity, bottom surface properties, sensory cavity and porosity, odor flavor and taste, sensory firmness and softness of texture were negatively correlated to PC2 axis while other bread and sourdough characteristics were positively correlated to PC2 axis. As clearly revealed in the PCA plot (Fig. 3), breads with selected characteristics traditionally associated with consumers' preference (sensory aspects) were those with interaction of LAB and baker's yeast (A + C, B + C and A + B + C). This interaction resulted in the decrease of hardness value during 7 days after breadmaking. While, specific volume of bread and acidity of sourdough

Fig. 3 Principal component analysis biplot on properties of sourdoughs and breads containing date seed flour; A: *Lb. plantarum*; B: *Lactobacillus brevis*; C: *Saccharomyces cerevisiae*; S.V.: specific volume; H_t is the bread hardness at t time; k is a rate constant and n is the Avrami exponent; Fractal: fractal dimension; CWT: cell wall thickness; Form: form and shape; USP: upper surface properties; BSP: bottom surface properties; Cavity: cavity and porosity; Odor: odor, flavor and taste; Chewing: chewing ability; Softness: softness and firmness of texture

were increased. The results depicted by PCA seemed to be in accordance with the results discussed above.

Correlation of instrumental and sensory properties of sourdough bread using PLSR method

Multivariate techniques can be effectively applied to establish relationships between instrumental and sensory descriptive data. It is known that statistical methods frequently used can be either asymmetric or symmetric (Dijksterhuis 1994). The asymmetric methods (as PLSR) are especially capable of predicting one data set from the other (Martens and Martens 2001) while symmetric methods (as PCA) simply describe the relationship between data sets. Several research workers (Hejri-Zarifi et al. 2013; Pourfarzad et al. 2012) have attempted to correlate quality and shelf life of bakery products to various chemical, rheological and sensory characteristics. PLSR was applied to investigate the relationship between instrumental X and sensory Y data. The prediction of sensory attributes by instrumental measurements is of paramount importance in food industry as it provides much information about the

acceptability and quality of the final product. Moreover, the determination of quality profile of sourdough bread by instrumental measurements has the advantages of high reproducibility, convenience and directness against the assessment of sensory attributes (Sabanis et al. 2009). Thus, six instrumental properties, which had the most significant interrelationships with other properties, were used as predictors: acidity of sourdough, bread hardness at 2 h after breadmaking (H_t), specific volume, lightness, average size and area fraction. The regression equations output to predict important parameters are given in Table 6. These high coefficients are an evidence of the applicability of the regression model between the ranges of variables included.

Conclusions

The significant role of process parameters and their partly strain dependent influence on technological activity of pulverized date seed sourdough were confirmed in this study. This study also shows significance of frequent interactions between LAB and

Table 6 Partial least squares regression (PLSR) models for sensory features of fresh Barbari bread containing sourdoughs of date seed flour

Sensory attributes	Mathematical models	R ²
Form and shape	$-9.252 - 0.817 \text{ S.V.} + 0.015 H_t + 0.278 L^* - 0.094 \text{ average size} + 0.039 \text{ area fraction} + 1.992 \text{ acidity}$	95.03
Firmness and softness of texture	$-23.985 - 1.571 \text{ S.V.} + 0.033 H_t + 0.561 L^* - 0.004 \text{ average size} + 0.068 \text{ area fraction} + 4.631 \text{ acidity}$	93.60
Cavity and porosity	$-17.059 - 0.439 \text{ S.V.} + 0.027 H_t + 0.388 L^* + 0.698 \text{ average size} - 0.017 \text{ area fraction} + 1.849 \text{ acidity}$	90.35
Upper surface property	$-6.556 - 0.497 \text{ S.V.} + 0.011 H_t + 0.224 L^* + 0.141 \text{ average size} + 0.004 \text{ area fraction} + 1.102 \text{ acidity}$	72.71
Bottom surface property	$6.575 - 0.004 \text{ S.V.} - 0.004 H_t - 0.060 L^* - 0.354 \text{ average size} + 0.038 \text{ area fraction} - 0.483 \text{ acidity}$	42.37
Chewing ability	$-0.599 + 0.155 \text{ S.V.} - 0.004 H_t + 0.074 L^* + 0.282 \text{ average size} - 0.015 \text{ area fraction} + 0.116 \text{ acidity}$	94.20
Odor, flavor and taste	$-15.840 - 0.153 \text{ S.V.} + 0.027 H_t + 0.341 L^* + 0.438 \text{ average size} + 0.003 \text{ area fraction} + 1.963 \text{ acidity}$	93.82
Overall quality score	$-11.032 - 0.559 \text{ S.V.} + 0.016 H_t + 0.292 L^* + 0.157 \text{ average size} + 0.018 \text{ area fraction} + 1.873 \text{ acidity}$	96.28

SV: Specific volume; H_t : bread hardness at 2 h after breadmaking; L^* : Lightness; acidity: sourdough acidity

baker's, and the importance of taking these interactions into account for processing. A combination of LAB and baker's yeast for fermentation of pulverized date seed could be used to improve the sourdough acidity, quality, shelf life, sensory and image characteristics of Barbari flat bread. Studies of this kind are a pertinent choice for predicting effects of various fermentation conditions on date seed sourdough properties and give valuable information on fermentation conditions to achieve a desired product. It was proved that PCA is able to extract relevant information and offer an easy and promising approach for the interpretation of quality, shelf life, sensory and image properties of Barbari bread. Combining sensory responses and instrumental measurements by PLSR method gave valuable information in understanding and predicting the effect of different sourdoughs of pulverized date seed systems on sourdough and bread quality.

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