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Comparison of Properties of Breads Enriched with Omega-3 Oil Encapsulated in β-Glucan and *Saccharomyces cerevisiae* Yeast Cells

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Abstract

Background and objective: Flaxseed oil, as a potential source of polyunsaturated fatty acids, is susceptible to oxidation. Yeast cells of *Saccharomyces cerevisiae* and β-glucan can be used as biocompatible and biodegradable matrices for the protection of this nutritious oil from oxidation in foods enriched with omega-3 fatty acids. The aim of this study was to investigate quality properties of breads containing encapsulated and free flaxseed oils.

Materials and methods: Flaxseed oil was encapsulated in either yeast cells or β-glucan. Functional wheat bread samples were prepared using unencapsulated and encapsulated flaxseed oils. These were compared with control samples in terms of dough rheological and bread quality parameters.

Results and conclusion: Encapsulation significantly increased dough rheological properties (G′ and G″ values), firmness and density and decreased lightness, compared to control samples. Breads, containing flaxseed oil encapsulated in yeast cells, showed a lower peroxide index and a higher α-linolenic acid value, compared to two other samples containing oil samples. This showed a better protection of unsaturated fatty acids against deleterious oxidation reactions. Results of this study indicate that addition of microencapsulated flaxseed oil into breads helps preserve sensory properties of the control sample, compared to breads fortified with free flaxseed oil.

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1. Introduction

Flaxseed (*Linum usitatissimum* L.) and flaxseed oil are majorly composed of omega-3 fatty acid alpha-linolenic acid (52% of total fatty acids), phenolic component such as lignan secoisolariciresinol diglucoside with antioxidant properties (> 500 µg g^{-1}) and soluble and insoluble fibers [1,2]. Docosahexaenoic acid, alpha-linolenic acid and eicosapentaenoic acid are n-3 polyunsaturated fatty acids, showing characteristics of neurological improvement, anti-inflammatory effect and cardio-protection [3,4]. Microencapsulation, as a protection method against oxidative destruction of oils, can improve their resistance to environment conditions [5]. Crude oils are sensitive to oxidation due to high contents of unsaturated fatty acids as well as iron and copper ions [6]. Microcapsules consist of a shell (wall or external phase) and a core (internal phase). The internal phase may be composed of substances such as living cells, volatile agents, bioactive components, antioxidants and essential oils. Various microencapsulation techniques include drying by spray or freeze, coating by fluidized-bed, supercritical fluid, extrusion, polymerization, emulsification, electrospray and coacervation techniques [5]. Bread yeasts (*Saccharomyces* (*S.) cerevisiae*), in forms of dried or wet, plasmolysed or non-plasmolysed in blends with the active ingredients in water or water/organic

solvents, were used for encapsulation. In previous studies, various substances such as resveratrol, fish oil, enzyme, chlorogenic acid, limonene, curcumin, purslane seed oil and vitamin D_3 were encapsulated in yeast cells [7-10]. Results have shown that removal of the cell content by plasmolysis, hydrolysis or autolysis can improve efficiency of the encapsulation [8]. The most important reagent for plasmolysis is sodium chloride [9].

The β-glucan is a polysaccharide majorly composed of β-D-glucopyranose units linked through (1→6) glycosidic bonds in fungus [11,12] and (1→4) and (1→3) glycosidic bonds in plant sources with various molecular weight and structure, solubility and functional and biological behaviors [11]. The β-glucan, as a prebiotic component, can decrease serum cholesterol and glycemic response, improve weight management, immune system and useful gut microbial growth [13,14]. Shah et al. used β-glucan as an encapsulating agent with high efficiency in encapsulation of probiotic bacteria. Microorganisms were simply trapped in β-glucan capsules and protected against gastrointestinal stresses. The macroporous honeycomb-like structure of β-glucan has made it a good candidate for the entrapment of active compounds [15]. Mechanisms of encapsulation by this polysaccharide include entrapment and adsorption. To the best of the authors' knowledge, no reports are available on the use of yeast cells and β-glucan for the encapsulation of flaxseed oil. Therefore, the current study was carried out to encapsulate flaxseed oil in yeast cells and β-glucan alone and to produce functional breads containing micro-encapsulated flaxseed oil. These breads were compared to breads containing free oil in terms of quality properties.

2. Materials and methods

2.1. Materials

Commercial baking yeast cells of *S. cerevisiae* (Fariman, Iran) and oat β-glucans (MCRO, The Netherlands) were used alone as carriers for encapsulation of flaxseed oil. Phosphate buffer and tween 80 were purchased from Sigma, USA. Hexane, thiosulfate sodium, acetic acid, chloroform, iodoral potassium, ethanol, chloride sodium, chloride calcium and petroleum ether were purchased from Merck, Germany.

2.2. Preparation of the microencapsulated flaxseed oil powder

For yeast encapsulation, pretreatment of yeast cells was initially carried out by washing the cells with phosphate buffer (pH 6.8) followed by a plasmolysis step with sodium chloride (NaCl) solution (10% w v^{-1}) using shaking incubator (Jal Tajhiz GTFL50, Iran) at 180 rpm for 48 h at 55ºC. After centrifuging and washing, plasmolysed cells were freeze-dried [7]. Flaxseed oil loaded yeast microcapsules were prepared by blending 10 g of flaxseed oil with 40 g of deionized water containing 3% v v^{-1} Tween 80 to produce o/w emulsion using ultra-Turrax (Turrax IKA T25-Digital Ultra, Germany) at 10,000 rpm for 5 min. This step was carried out using ice bath to avoid temperature increase during homogenization and oxidation. Plasmolysed cells were added to emulsion to reach a 1:2 flaxseed oil: yeast weight ratio (w w^{-1}) (the ratio was calculated by initial experiments). Suspension was incubated with agitation at 180 rpm for 12 h at 40ºC using shaker incubator. Loaded microcapsules were separated from the emulsion by centrifuging at 8,965 ×g for 15 min and washing with distilled water to remove residues of unencapsulated flaxseed oil. Microcapsules were freeze-dried using freeze drier at -80ºC for 14 h (Christ ALPHA 2-4, Germany). Flaxseed oil loaded β-glucan microcapsules were produced by adding β-glucan instead of yeast cells to the emulsion as described previously.

2.3. Loading capacity (LC)

Percentage of LC was calculated using the following equation:

$$\text{LC (g kg}^{-1}) = \frac{\text{Total oil mass (g)} - \text{Surface oil mass (g)}}{\text{Dry mass of microcapsules (kg)}} \quad (1)$$

Total oil content of the microcapsules was assessed using Soxhlet extraction and petroleum ether based on a method by Kavosi et al. [7]. In brief, loaded microcapsule samples were transferred to a Soxhlet extractor in a thimble. A pre-weighted evaporation flask containing 100 ml of petroleum ether was connected to the extractor. After 2.5 h, solvent was evaporated using vacuum rotary evaporator at 40°C and dried to a constant weight. The oil weight was calculated using the mass difference between the oil and dry flasks. The surface oil was collected using hexane extraction at ambient temperature [7].

2.4. The α-linolenic acid assessment of flaxseed oil

The α-linolenic acid (C18:3) content was assessed using gas chromatography in free and encapsulated oils and in breads containing free and encapsulated oils. Oil extraction and fatty acid derivatization were carried out based on a previously described method [16]. The chromatographic profile was generated and the ALA content was determined using peak area measurement and gas chromatography device (Agilent Technologies 7890 Series, USA) equipped with a BPX70 column (100 m × 0.25 mm × 0.2 µm; Agilent Technologies, USA). Injector and detector temperatures were set at 250 and 280°C, respectively. Temperature gradient was set at 120°C for 1 min (10°C min^{-1}), 175°C for 10 min (5°C min^{-1} up to 210ºC) and 27 min at 210ºC.

2.5. Preparation of the functional breads

Based on the AACC 10-10B with minor modification, breads were formulated [17]. Wheat flour (100 g), bread yeast (1 g), sodium chloride (0.66 g), sugar (1.33 g), bread improver (1 g) and 40 ml of deionized water were mixed. Then, flaxseed oil powders microencapsulated with yeast

and β-glucan alone were added. Furthermore, samples containing free flaxseed oil were prepared as well as control samples. After fermenting, punching and proofing (35ºC for 1 h), four samples were baked at 180ºC for 30 min.

2.6. Rheological test of the functional bread doughs

The frequency sweep test was carried out using controlled stress rheometer (Physica MCR 301, Austria) and parallel plate geometry (40-mm diameter, 1-mm gap). Bread doughs were stored at 25 ± 1ºC during the measurements. Two various samples of each treatment were prepared and analyzed at two times. To calculate linear viscoelastic regions, strain sweeps were carried out at 1 Hz from 0.1 to 200% strain. Then, frequency sweep measurements were carried out at a strain of 0.01 and a range 0f 0.01-100 Hz and then calculated using Rheoplus/32 v.3.21 Software.

2.7. Quality properties of the functional breads

Loaf volume was calculated using seed displacement method [18]. Apparent density was calculated as a ratio of the weight to volume [19]. Moisture content was calculated according to AACC 44-15 [17]. Water activity (a_w) was calculated using a previously described method [20]. Texture of the slices (thickness of 10.0 mm) was analyzed at 25% force using texture analyzer (Lloyd Instruments TA Plus, UK) and TA4 probe (diameter of 1.5 mm) with load cell of 50 N and speed of 1 mm s^{-1}. Sensory acceptability was calculated according to AACC 2000 10-90 using verbal hedonic scale of five points from 1) disliked extremely to 5) liked extremely. Flavor, porosity, doughy/dry during chewing, crumb/crust color and hardness/softness of the samples were measured by 30 consumers at Days 1, 7 and 14 after baking [21]. The final score was calculated based on the following equation:

$$\text{Final score} = \text{Total experience} / \text{Total coefficient}$$

The color value was calculated using brightness (L^*), yellowness (b^*) and redness (a^*). Briefly, crumb images were taken using 14.5-mpixel compact camera (Sony, Japan) [21]. For peroxide value calculation, bread powder (10 g), chloroform (50 ml), methanol (25 ml) and 2.5% $CaCl_2$ solution (25 ml) were mixed in a tube. Alcoholic layer was separated by centrifuging at 13,000 ×g for 20 min and the mixture was titrated using 0.01 N $Na_2S_2O_3$ in the presence of starch reagents [22,23]. The peroxide value was calculated using the following equation:

Peroxid value (mEq kg^{-1}) = (titrant volume for sample - titrant volume for blank) × 0.01 N × 1000 × 5 / sample weight (g)

2.8. Statistical analysis

Statistical analysis was carried out using SPSS Software (IBM Analytics, USA). Results were expressed as mean and standard deviation. Duncan's Test was used to show significant differences between the samples at $P \leq 0.05$. Tests were repeated three times for each sample.

3. Results and discussion

3. 1. Loading capacity (LC)

In this study, feasibility of β-glucan and *S. cerevisiae* cells were investigated as various carriers for the encapsulation of flaxseed oil. Then, effects of these microcapsules on quality properties of the fortified breads were assessed. The LC percentage was determined for calculating quantities of the microcapsules needed to reach a fixed flaxseed oil level in bread formulations. The LC values included 39.35% ± 0.69 and 37.57% ± 1.25 for flaxseed oil loaded yeast cells and β-glucan, respectively. No significant differences were seen between the two formulations. Quantity of the flaxseed oil added to the bread formulations was based on the recommended quantity of Omega-3 fatty acids by the International Society for the Study of Fatty Acids and Lipids (0.5 g ω-3 day^{-1}) [16]. Based on the values recorded for LC and with respect to 34.73% of ALA in flaxseed oil, addition of 3.65 g of oil-loaded yeast cells and 3.83 g of oil-loaded β-glucan to 100 g of flour represented 0.5 g of ALA per portion.

3.2. Rheological properties of the functional bread dough

For frequency sweep measurement of the dough samples, linear viscoelastic regions were calculated using strain sweep. A constant strain of 0.01% was set in frequency range of 0.01-100 Hz. Based on the curve (Fig. 1), G′ was dominant over the frequency range, which represented for the elastic response of all samples; thus, showing a solid-like behavior. Samples containing oil-loaded β-glucan microcapsules showed G′ values higher than G′ values the other samples did. Distance between G′ and G″ of these samples was the highest, showing further rigidity in structures of doughs. In contrast, samples with free flaxseed oil showed the lowest G′ and weak structures. According to Skendi et al. starchy granules might be surrounded by β-glucan chains in β-glucan containing doughs [24]. In fact, β-glucan could bind to water and decrease free water due to its high water binding capacity, resulting in increased viscosity and G′ and G″ values. These results were similar to results by Hager et al., which concluded a higher added water level and a further elastic dough as a result of oat β-glucan addition [25]. Hamed reported that use of 10% of barley flour in bread formulations led to further dough elasticity and firmness compared to controls due to high contents of β-glucan in barley flours [26]. Brennan and Cleary found that bread doughs containing 5% of Glucagel included a significantly higher resistance to extension compared to control doughs with no Glucagel [27]. The water binding capacity of β-glucan chains may cause loss of extensibility and hence weaken the gluten network [28]. Symons and Brennan reported that gelling effects of β-glucan and its elastic nature resulted in changes in rheological behaviors of doughs containing β-glucan [29].

Addition of free oil in a dough system makes the gluten structure weak and hence decreases viscosity. Lubrication effect and plasticity development of oils in food powder products could be two major reasons for this effect [30]. Maache-Rezzoug et al. found that the lubricating effect of oils led to decrease of water necessary to achieve a soft consistency in wheat doughs [31]. As frequency sweep tests exhibited time-dependent shear behaviors [32] for samples containing β-glucan encapsulated oils towards lower frequencies, slope of the G′ curve substantially decreased, showing further decrease of dough stiffness by time. However, dough structural strength is maximum at rest. On the contrary, slope of the G′ curve in samples containing free oil was in parallel to x-axis; therefore, dough long-term behavior was constant.

3.3. Volume, density and porosity index of functional breads

The volume index of breads containing oil-loaded β-glucan microcapsules included 380.10 cm^3, which was significantly lower than that of other samples (Table 1). The control sample included the lowest volume. Moreover, bread density increased with the addition of microencapsulated particles. Encapsulated breads with β-glucan significantly included a higher density ($P \leq 0.05$), compared to that other samples did. Gokmen et al. showed that using 1 and 10% of nanoparticles, containing omega-3, could decrease loaf volume and increase density [33]. Lu et al. showed that replacement of shortening with microencapsulated omega-3 (1, 1.75 and 2.5%) did not include significant effects on specific volume of breads ($P>0.05$), compared to control samples [22]. Conto et al. reported that the reason for decreased volume of breads could be due to the dilution of gluten by adding microcapsules or by decreased CO_2 retaining during baking time [34]. Based on Fig. 1, β-glucan addition created a further viscose dough with high G′ and G″ values. As a result, air bubbles could not be easily trapped inside dough structure. Therefore, an increase in viscosity of the bread doughs could decrease volume and increase density of the breads [35]. The porosity values of breads are shown in Table 1. The highest and lowest porosity indices were linked to control samples and samples with free flaxseed oil, respectively; however, differences between the samples were not statistically significant.

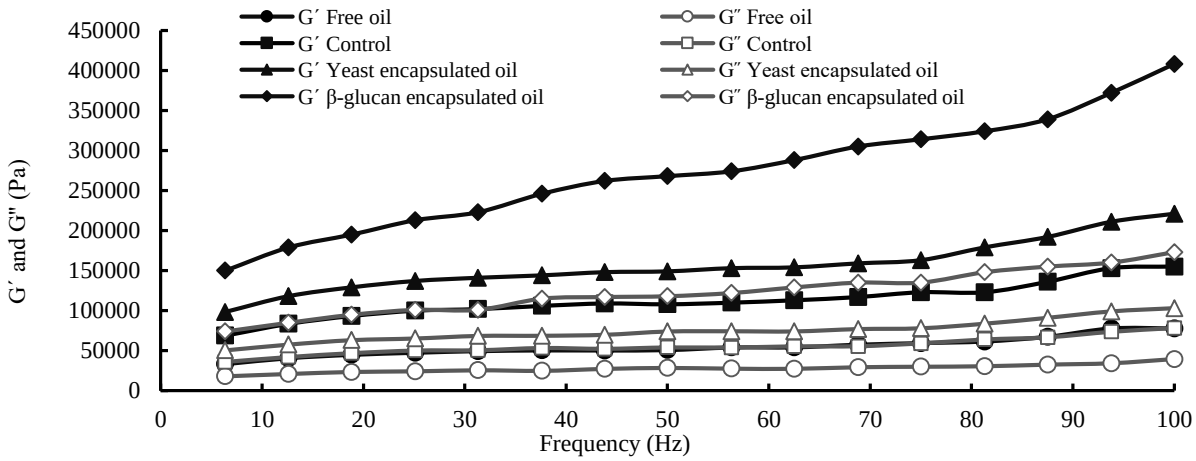

Figure 1. Frequency sweep of moduli G′ (filled symbols) and G″ (open symbols) for the bread dough samples

Table 1. Physical properties of the breads samples[a,b]

Sample	Volume (cm^3)	Density (g/cm^3)	Porosity	Color		
				L*	a*	b*
Control	514.06±5.564[a]	0.381±0.022[c]	0.602±0.021[a]	63.05±0.912[a]	1.42±0.432[b]	24.18±0.551[b]
Yeast encapsulated oil	420.50±6.421[c]	0.432±0.013[b]	0.598±0.017[a]	55.97±0.348[c]	4.55±0.398[a]	31.55±0.566[a]
β-glucan encapsulated oil	380.10±4.851[d]	0.511±0.037[a]	0.587±0.013[a]	57.44±0.769[bc]	3.67±0.127[ab]	28.11±0.931[ab]
Free oil	465.32±8.912[b]	0.412±0.032[bc]	0.450±0.043[a]	60.62±0.661[ab]	2.08±0.199[ab]	26.83±0.383[ab]

[a] Different letters show significant differences of data ($P \leq 0.05$)
b L*: lightness, a*: redness and b*: yellowness

3.4. Color value of the functional breads

Addition of flaxseed oil in unecpsulated and encapsulated resulted in a lighter color in bread samples (Table 1). Encapsulated samples with β-glucan were darker, compared to other samples. The highest values of a* and b* were associated to samples containing oil-loaded β-glucan microcapsules and controls, respectively. Lu et al. reported that replacement of shortening with microcapsulated omega-3 at levels 1 and 1.75% included no significant

effects on a* and b* (P>0.05) [22]. In contrast, Conto et al. reported that increased microcapsules containing omega-3 decreased lightness of the breads due to microcapsule interfere with production of the gluten structure [34].

3.5. Peroxide index of the functional breads during storage

The peroxide value of bread enriched with free oil was significantly higher than other samples on 3, 5 and 7 days after baking (Table 2). Sample encapsulated with yeast had the lowest peroxide value during storage although bread containing oil-loaded yeast cells had no significant difference (P>0.05) compared to bread containing oil-loaded β-glucan microcapsules. The reason for high peroxide value in the samples containing free oil can be due to the large amount of oil on the surface of bread that is exposed to oxidation. For yeast encapsulation samples, phospholipid membrane especially plasmolysed type acts as a liposome and stabilizes oil within cell and prevents oil oxidation [36]. Similar results have been reported regarding the microencapsulation of resveratrol and purslane seed oil by yeast cells and their physical barrier role against oxidation by Shi et al. [37] and Kavosi et al. [7].

3.6. The α-linolenic acid content

In this study, ALA was selected as an index to investigate effects of encapsulation and bread baking processes on flaxseed oil fatty acid composition. The content of ALA in encapsulated oils was similar to free oils (Table 3) as ALA contents were nearly 90% of the initial content for the two formulations. This decrease is attributed to the partial degradation of fatty acids during the encapsulation process. Similar decreases in ALA content were previously reported by other studies after linseed oil microencapsulation with Arabic gum, maltodextrin and methyl cellulose [38]. Analysis of the bread samples showed an ALA content of 8 to 22% in various formulations, which indicated a great decrease of ALA. The highest decrease was found in samples containing free oil and the lowest in samples containing oil loaded in yeast microcapsules. Several factors could contribute to this dramatic decrease such as promotion of accelerated oxidation of the unsaturated fatty acids due to bread making conditions (such as water addition, dough proofing and baking at 180°C). Moreover, Results of ALA values in breads containing encapsulated oil generally include high SD values due to inefficient mix of flour with oil-loaded microcapsule powder [16]. However, relatively acceptable content of ALA in breads containing oil-loaded yeast microcapsules indicated that yeast cells could act as a potential protective shell to preserve entrapped oil. Results were similar to peroxide index results.

Table 2. Values of peroxide, moisture and firmness of the bread samples during storage[a]

Samples	Storage day	Peroxide	Moisture	Firmness
Control	1	0.26 ± 0.011^{aB}	30.68 ± 1.411^{aA}	123.961 ± 7.23^{bcC}
	3	0.35 ± 0.018^{bAB}	26.3 ± 1.113^{aAB}	158.656 ± 6.91^{bcC}
	5	0.41 ± 0.023^{bA}	22.54 ± 1.093^{bBC}	204.114 ± 9.56^{bB}
	7	0.47 ± 0.015^{bA}	19.21 ± 1.201^{bC}	267.712 ± 9.43^{abA}
Flaxseed oil loaded yeast cells	1	0.24 ± 0.010^{aB}	28.5 ± 1.367^{abA}	162.528 ± 5.87^{abC}
	3	0.27 ± 0.022^{bAB}	26.59 ± 1.276^{aAB}	191.221 ± 6.89^{bC}
	5	0.33 ± 0.025^{bAB}	25.57 ± 1.510^{abAB}	249.432 ± 8.95^{aB}
	7	0.36 ± 0.017^{cA}	23.12 ± 1.243^{abB}	295.022 ± 9.86^{aA}
Flaxseed oil loaded β-glucan	1	0.26 ± 0.012^{aB}	29.63 ± 2.071^{abA}	190.415 ± 7.33^{aC}
	3	0.33 ± 0.020^{bAB}	27.32 ± 1.332^{aAB}	246.321 ± 8.28^{aB}
	5	0.42 ± 0.027^{bAB}	27.09 ± 1.512^{aAB}	283.243 ± 9.22^{aAB}
	7	0.46 ± 0.019^{bcA}	25.5 ± 1.167^{aB}	301.661 ± 9.65^{aA}
Free flaxseed oil	1	0.28 ± 0.011^{aD}	26.66 ± 1.340^{bA}	102.822 ± 5.44^{cB}
	3	0.46 ± 0.024^{aC}	24.95 ± 1.685^{aAB}	125.356 ± 6.94^{cB}
	5	0.65 ± 0.046^{aB}	22.43 ± 1.088^{bBC}	198.581 ± 6.73^{bA}
	7	0.93 ± 0.054^{aA}	19.14 ± 1.144^{bC}	238.652 ± 7.41^{bA}

[a] Different small and capital letters respectively show significant differences in bread type and storage time (P≤0.05)

Table 3. The α-linolenic acid content of the samples after encapsulation process and after bread baking process[a,b].

Sample	After encapsulation	After bread baking
Free flaxseed oil	34.73 ± 0.92^{aA}	8.81 ± 0.97^{cB}
Flaxseed oil loaded β-glucan	31.25 ± 1.89^{aA}	17.42 ± 0.95^{bB}
Flaxseed oil loaded yeast cells	30.46 ± 1.46^{aA}	22.06 ± 1.04^{aB}

[a] Data reported in average values ±SD (standard deviation)
[b] Values in each row and column with different letters are significantly different (P≤0.05)

3.6. Moisture and a_w indices of the functional breads during storage

Comparison between the bread moisture and a_w after one day of baking is shown in Fig. 2. Results showed that samples included no significant differences in terms of a_w. Although, samples containing free flaxseed oil and control samples included the lowest and highest moisture contents, respectively, and differences between these samples were significant (P≤0.05). On Days 1 and 3 of baking, samples showed no significant differences (P>0.05) in moisture

contents (Table 3). On Days 5 and 7 of baking, the highest moisture value with significant difference (P≤0.05) was detected in samples with β-glucan, compared to samples with encapsulated free flaxseed oil and yeast cell. Based on the rheological properties, regions of bulk free water were occupied by a highly viscous β-glucan dispersion, resulting in increased viscosity and hence higher G′ and G″ values. The β-glucan is considered as hydrocolloids [39]. Hydrocolloids include hydrophilic properties that increase absorption and preservation of water [40]. Pasrija et al reported that microencapsulation of polyphenols with β-cyclodextrin increased its moisture content due to free hydrophilic sites [41]. A possible reason for the low moisture content in yeast microencapsulation is due to phospholipid membranes in yeast cells [36], which act as physical barriers and prevent moisture diffusion.

3.7. Texture analysis of the functional breads during storage

Firmness of the bread enriched with free oil was significantly lower than that of other samples on Days 1, 3, 5 and 7 of baking (Table 2). However, free oil samples showed no significant differences (P>0.05), compared to control samples. Samples containing flaxseed oil-loaded β-glucan microcapsules included the highest firmness during storage. However, these samples showed no significant differences (P>0.05), compared to that breads containing oil-loaded yeast cells did on days 1, 5 and 7 of baking. In addition, firmness increased in all samples during storage. Texture properties of the breads depended on gelatinization of the starch [41]. Beikzadeh et al. reported that ability of hydrocolloids bonding to water and preserving it during storage with effects on starch changed texture of the products [40]. As a result, high moisture retention capacity in samples including β-glucan increased dough viscosity and created further elastic doughs and firmness breads, compared to other samples. This results were similar to results by Hager et al. and Skendi et al. [24,25]. Furthermore, decreased firmness of the bread samples containing free flaxseed oil could be explained by weakened gluten networks and decreased viscosity of doughs due to the presence of oils [30].

3.8. Sensory evaluation of the functional breads during storage

Sensory evaluation of the functional bread samples is described in Table 4. Control samples included significantly higher sensory scores (P≤0.05), compared to that samples including free flaxseed oil did. However, control samples included no significant differences (P>0.05), compared to breads containing oil-loaded yeast and β-glucan microcapsules. Porosity and crumb color of all samples included no significant differences. As previously stated, addition of microcapsules increased color lightness of the samples since addition of β-glucan produced darker samples. Therefore, low and high crust color scores of the samples containing yeast and β-glucan could be due to the highlighted reason. Breads containing free oil included the lowest overall sensory score that might be due oily nature of the products. Moreover, free flaxseed oil increased peroxide value and included negative effects on flavor. In softness/hardness, samples including microcapsules with yeast and β-glucan showed a low score due to the high firmness value. Based on the results, addition of encapsulated oil did not change sensory properties of the products, compared to control samples.

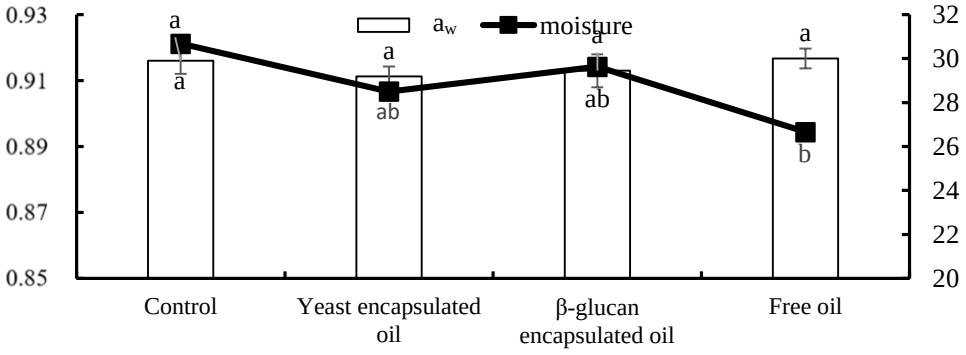

Figure 2. Comparison between the moisture and a_w of the breads on Day 1 of baking

Table 4. Sensory evaluation of the functional breads encapsulated with flaxseed[a]

Bread samples	Porosity	Crumb color	Crust color	Softness/Hardness	Flavor	Overall sensory score
Control	4.2±1.01[a]	4.50±0.67[a]	4±0.94[a]	4.5±0.86[a]	4.25±0.73[a]	4.12±0.81[a]
Free flaxseed oil	4±0.87[a]	4.25±1.12[a]	4.1±0.86[a]	4.1±0.72[a]	3.50.0.59[b]	3.70±0.55[b]
Flaxseed oil-loaded β-glucan	4.15±0.91[a]	4.27±0.75[a]	4.15±0.73[a]	3±059[c]	4.1±0.64[a]	3.97±0.72[ab]
Flaxseed oil-loaded yeast cells	4.1±1.05[a]	4.15±0.81[a]	3.5±0.55[b]	3.5±0.61[b]	4.15±0.54[a]	3.94±0.59[ab]

[a]For each property, different letters show significant differences (P≤0.05)

4. Conclusion

In general, flaxseed oil-loaded yeast cells and β-glucan were successfully prepared. The value of LC in oil-loaded yeast cells was higher than that in β-glucan capsules. Properties of the fortified breads were affected by the addition of encapsulated and unencapsulated flaxseed oils. The highest viscosity, rheological parameters (G′ and G″) and firmness and the lowest volume were reported in dough breads containing oil-loaded β-glucan microcapsules. Samples containing oil encapsulated in yeasts included the highest protective effect against oil oxidation during and after the baking process. Addition of flaxseed oil in free or encapsulated forms resulted in decreased color lightness of the bread samples, compared to control samples. In conclusion, results suggest possible use of oil-loaded yeasts and β-glucan microcapsules for the fortification of food products with no effects on bread sensory properties.

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6. Conflict of interest

The authors declare no conflict of interest.

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مقایسه خواص نان‌های غنی شده با روغن حاوی امگا ۳ کپسوله شده در بتاگلوکان و سلول‌های مخمر *ساکارومیسس سرویزیه*

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چکیده

سابقه و هدف: روغن دانه کتان، به عنوان یک منبع بالقوه اسیدهای چرب چندغیراشباعی، به اکسایش حساس است. سلول‌های مخمر *ساکارومیسس سروزیه* و بتاگلوکان به‌عنوان ماتریس‌های زیست سازگار و زیست تخریب پذیر برای حفاظت این روغن مغذی از اکسایش در مواد غذایی غنی شده با اسیدهای چرب امگا ۳ می‌توانند مورد استفاده قرار گیرند. هدف از این مطالعه، بررسی ویژگی‌های کیفی نان‌های حاوی روغن کتان ریزپوشانی شده و آزاد می‌باشد.

مواد و روش ها: روغن دانه کتان به صورت جداگانه در سلول‌های مخمر و بتاگلوکان ریزپوشانی شد. نمونه‌های نان گندم فرا سودمند حاوی روغن کتان آزاد و ریزپو شانی شده تولید شد. ویژگی های رئولوژیکی خمیر و خواص کیفی نان تولیدی با نمونه‌های شاهد مقایسه شد.

یافته‌ها و نتیجه‌گیری: ریزپوشانی به طور معنی‌داری خواص رئولوژیکی خمیر (شاخص های G′ و G″) ، سفتی بافت و چگالی را افزایش و روشنی بافت را در مقایسه با نمونه های شاهد کاهش داد. نان های حاوی روغن دانه کتان ریزپوشانی شده در سلول‌های مخمر عدد پراکسید پایین‌تر و میزان آلفا لینولنیک اسید (ALA) بیشتری در مقایسه با دو نمونه حاوی روغن داشتند. این نتیجه نشان دهنده محافظت بهتر از اسیدهای چرب غیر اشباع در برابر واکنش‌های مخرب اکسایش است. نتایج این مطالعه نشان داد که در مقایسه با نان های غنی شده با روغن کتان آزاد، افزودن روغن دانه کتان ریزپوشانی شده به نان به حفظ خواص حسی آن کمک می کند.

تعارض منافع: نویسندگان اعلام می‌کنند که هیچ نوع تعارض منافعی مرتبط با انتشار این مقاله ندارند.

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- بتاگلوکان

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