Effects of addition of different fibers on rheological characteristics of cake batter and quality of cakes

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Abstract The aim of this study was to investigate the effects of addition of dietary fibers on rheological properties of batter and cake quality. Wheat flour was replaced by 5 and 10% (wt%) oat, pea, apple and lemon fibers. All cake batters showed shear thinning behavior. Incorporation of fibers increased consistency index (k), storage modulus (G') and loss modulus (G''). As quality parameters, specific volume, hardness, weight loss, color and microstructure of cakes were investigated. Cakes containing oat and pea fibers (5%) had similar specific volume and texture with control cakes which contained no fiber. As fiber concentration increased, specific volume decreased but hardness increased. No significant difference was found between weight loss of control cake and cakes with oat, pea and apple fibers. Lemon fiber enriched cakes had the lowest specific volume, weight loss and color difference. When microstructural images were examined, it was seen that control cake had more porous structure than fiber enriched cakes. In addition, lemon and apple fiber containing cakes had less porous crumb structure as compared to oat and pea containing ones. Oat and pea fiber (5%) enriched cakes had similar physical properties (volume, texture and color) with control cakes.

Keywords Oat · Pea · Lemon · Apple · Dietary fiber

Introduction

The relationship between food and health has an increasing impact on the food industry due to the importance of healthy diet on the quality of life. Therefore, nutraceutical components coming from plant sources are good choices to develop new food with special health-enhancing characteristics. Dietary fiber is one of the important nutraceutical components that can be used in food industry (Lebesi and Tzia 2011).

Dietary fiber is defined as the edible part of plants or analogous carbohydrates which is resistant to digestion and adsorption in the human small intestine with complete or partial fermentation in the large intestine (Gelroth and Ranhotra 2001). Dietary fiber can be categorized as insoluble and soluble dietary fiber. The main components of dietary fiber are cellulose, lignin, hemicellulose, pectin, gums and starch. Among these, cellulose and resistance starch are insoluble but the others are soluble (Raghavendra et al. 2004).

In recent years, dietary fiber has received increasing attention from researchers and industry due to its beneficial effects on the reduction of coronary heart-related diseases, cholesterol levels, diabetes incidence and risk of colon cancer (Lairon et al. 2005). An adequate intake for dietary fiber is considered to be about 14 g/1000 kcal per day for adults (Wheeler and Pi-Sunyer 2008). Therefore, the development of fiber enriched cakes is one of the efficient ways to increase fiber intake.

In addition to health benefits, dietary fiber is also an important constituent due to its functional properties. It can be used to modify the consistency, texture and sensory characteristics of the fiber supplemented food products (Collar et al. 2009). In addition, it can be used to enhance food stability during production and storage (Lebesi and

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Tzia 2011). However, the addition of fibers sometimes causes a negative effect on the quality of baked product since excess of insoluble dietary fibers has an adverse effect on the formation of gluten network (Chang et al. 2015). The most important problems are reduction of loaf volume, increase in crumb firmness and poor sensory characteristics. Kaack et al. (2006) produced bread enriched with potato fiber containing high level of insoluble fiber and reported that potato fiber increased the hardness and gumminess of bread. Wu et al. (2012) stated that breads containing excess wheat bran had significantly higher hardness and lower elasticity and sensory score than control breads.

Due to high consumption of bakery products, they can be potential carriers of dietary fibers. Several studies have been carried out showing the effect of fiber addition on quality of breads. Wang et al. (2002) used carob fiber, inulin and pea fiber as fiber-enriching agents in bread making. Furthermore, many forms of dietary fiber have been used in bakery products such as rice bran (Abdul-Hamid and Luan 2000), potato fiber (Kaack et al. 2006) and pear cactus fiber (Guevara-Arauz et al. 2014). However, relatively less research was conducted on the effects of different dietary fiber addition on cake quality characteristics (Sudha et al. 2007; Gularte et al. 2012). In addition, in literature, there is no study about the effects of addition of pea and lemon fibers on cake quality. Moreover, the effects of pea, oat, lemon and apples fibers on batter rheology and cake quality parameters (volume, texture, color) were not compared so far.

Dietary fiber types have different nutritional and functional properties due to their differences in their structure and chemical composition. From this point of view, the effects of different dietary fiber sources on rheological properties and quality of cakes may change. The aim of this study was to examine the effect of dietary fiber from lemon, apple, oat and pea on the rheological properties of batter and quality characteristics of cakes.

Materials and methods

Materials

Cake flour containing 27% wet gluten, 0.65% ash, 13.5% moisture/100 g flour, starch 72–74%, lipids 0.4–0.6 was obtained from Basak Flour Factory Inc. (Ankara, Turkey). Oat, pea, lemon and apple fibers in powder form were supplied by Arosel Food Industry Co. Inc. (İstanbul, Turkey). Egg white powder was provided from ETI Food Industry Co. Inc. (Eskisehir, Turkey). Other ingredients like sugar, non-fat dry milk (35.10 g protein/100 g nonfat dry milk, 52.19 g carbohydrate/100 g nonfat dry milk,

0.72 g fat/100 g nonfat dry milk) (Bağdat Baharat, Ankara, Turkey), salt, shortening (80.1 g total fat content/100 g) (Sana Margarine, Unilever, İstanbul, Turkey) and baking powder (sodium bicarbonate/tartaric acid) (Dr. Oetker, İstanbul, Turkey) were bought from local markets in Ankara.

Dietary fiber determination

Total, insoluble and soluble dietary fibers of oat, pea, lemon and apple fibers in powder form were analyzed by AOAC method 991.43 (1992).

Water binding capacity

Fiber powders (250 mg) was taken in 50 ml centrifuge tube. 25 mL of distilled water was added to tube and it was hydrated for 1 h. Then, samples were centrifuged (30 min, 10,000g), the supernatant was discarded carefully and weight of residue was measured. Water binding capacity was expressed as the amount of water retained per gram of dry sample (g g^{-1} dry matter) (Lecumberri et al. 2007).

Cake batter preparation

Cake batter formulation based on flour weight contained 100% sugar, 25% shortening, 9% egg white powder, 12% non-fat dry milk, 3% salt, 5% baking powder and 90% water (Sakiyan et al. 2011). Wheat flour was replaced by 5 and 10% (wt%) oat, pea, lemon and apple fibers. Cakes with no direct addition of fiber were used as control.

While preparing cake batter, all dry ingredients (sugar, egg white powder, non-fat dry milk, salt, baking powder, flour and fibers) were mixed with a mixer having wire whip (Kitchen Aid, 5K45SS, USA) for 1 min at low speed (85 rpm). Then, water and melted shortening were added and mixed for 1 min at low speed (85 rpm) then 2 min at high speed (140 rpm) and 1 min at low speed (85 rpm) again. Prepared cake batter samples (100 g each) were poured into glass cake cups of 8.7 cm in diameter and 4.8 cm in height.

Rheological analysis

The rheological behavior of batter was measured using a controlled strain rheometer (Kinexus dynamic rheometer, Malvern, UK) with parallel plate geometry (having 2 cm diameter) with a 1 mm gap. The sample was placed between the plates and the edges were carefully trimmed with a spatula. For flow measurement, shear stress values were recorded for shear rates varying between 0.1 and 100 s^{-1} . In dynamic oscillatory experiments, amplitude tests with varying strains of 0.01–100% were applied to

samples at a fixed frequency of 1 Hz to measure the linear viscoelastic region of samples. Then, 0.1% strain rate was determined from amplitude test. Frequency sweep tests from 0.1 to 10 Hz were conducted and elastic (G') and loss (G'') modulus values were obtained. For each experiment, average of three measurements were recorded.

Baking

Baking was performed in convection oven (9540 H DG, Arçelik A.Ş., İstanbul, Turkey) preheated to 175 °C and five batter samples (100 g each) were baked for 24 min. Baking of cakes were replicated twice.

Quality analysis of cakes

After baking, cakes were cooled to 25 °C for 1 h. Their specific volume, texture, weight loss, color and microstructure were determined. Three replications were used for each treatment in all of the quality measurements.

Specific volume

Specific volumes of cakes were measured by rape seed displacement method (AACC 1990).

Texture

After the cake samples were cooled to 25 °C for 1 h, cubic cake samples were cut from center of the cake (2.5 cm × 2.5 cm × 2.5 cm). Crumb hardness (N) was measured by using texture analyzer (Lloyd Ins., England, UK) with compression test. Samples were compressed to 25% of their original height at a speed of 55 mm/min. A cylindrical probe with a diameter of 10 mm and a load cell of 50 N was used.

Weight loss

Percent weight loss of cake samples were calculated by using the Eq. 1:

$$WL(\%) = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

where, W_i represents initial weight of cake batter (g), W_f represents weight of cake sample (g) just after baking.

Color measurements

Color of cake crust was measured by color meter (Konica Minolta Spectrophotometer, CM-5, Japan) as described by Ozkahraman et al. (2016). Values of L^* , a^* and b^* were recorded (CIE coordinates). L^* denotes lightness and

darkness, a^* denotes redness (+) and greenness (−) and b^* denotes blueness (−) and yellowness (+). ΔE^* represents the color change and can be calculated as shown in the Eq. 2:

$$\Delta E^* = \left[(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2 \right]^{1/2} \quad (2)$$

L_0^* , a_0^* and b_0^* values are the reference values obtained from barium sulphate which were 93.2, −1.4 and 0.12, respectively.

Microstructural analysis of fibers and cakes

Cake samples were cut into 0.5 cm × 0.5 cm cubic and freeze dried. Powder fibers and the dried cake samples were coated with gold palladium and microstructural images were obtained by scanning electron microscope (JSM-6400-NORAN, Tokyo, Japan). Images of fiber and cake crumbs were taken at 400× and 30× magnification level, respectively.

Statistical analysis

Analysis of variance (ANOVA) was used to determine whether there were significant differences between fiber types and concentrations or not. MINITAB (version 16, State College, PA, USA) was used. If significant differences were found, Tukey's Multiple Comparison Test was used for comparisons ($\alpha = 0.05$).

Results and discussion

Fiber characterization

The composition (total, insoluble and soluble fiber content) of fiber from different sources is shown in Table 1. All fibers were composed of mainly insoluble fibers so they were considered as insoluble fibers instead of soluble fibers. Several researchers agreed that pea, oat, apple and lemon fibers had higher amount of insoluble fibers than soluble fiber (Rosell et al. 2009; Bouaziz et al. 2010; Bchir et al. 2014; Fu et al. 2015). Amongst fibers, the highest amount of soluble fiber (19.39/100 g) belonged to lemon fiber. It was followed by apple fiber having 12.56/100 g soluble dietary fiber content. Oat fiber had the highest insoluble and the lowest soluble dietary fiber amount.

Water binding capacities of fibers are also shown in Table 1. Chemical compositions of fibers are known to affect water binding ability. For example, cellulose and lignin tend to have low water binding capacity but hemicellulose and pectin have high water binding capacity. Cellulose and lignin are the main constituents of insoluble

Table 1 The composition and water binding capacity of fibers

Fiber type	Total dietary fiber (g/100 g)	Insoluble dietary fiber (g/100 g)	Soluble dietary fiber (g/100 g)	Water binding capacity (g water/g solid)
Pea	84.25 ^b	76.36 ^b	7.89 ^c	4.70 ^a
Oat	90.35 ^a	83.85 ^a	6.50 ^d	4.27 ^a
Apple	75.02 ^c	62.46 ^d	12.56 ^b	5.31 ^a
Lemon	82.79 ^b	63.41 ^c	19.38 ^a	22.51 ^b

Columns having different letters are significantly different ($p \leq 0.05$)

dietary fibers (Kaack et al. 2006). However, hemicellulose and pectin are soluble fiber constituents (Raghavendra et al. 2004). In this study, the soluble fiber was shown be correlated with water binding capacity ($r = 0.92$, $p \leq 0.05$). Therefore, lemon fiber had the highest water binding capacity due to its highest soluble fiber content among other fibers. In the study of Weber et al. (1993), it was found that the water holding capacity values of sugar beet and orange fiber were higher than barley and oat fibers due to their high concentration of soluble fiber.

The microstructure of fibers also affects the water holding capacity, dough characteristics and product quality. Long fibers can be observed in oat fiber which was mainly composed of cellulose (Fig. 1). Oat fiber showed fibrous structures with thread like particles of different sizes. Pea fiber was formed of regular particles. However, apple and lemon fiber had coarser, irregular structure and larger particle size. The difference between structures of fibers could be due to the different amount of insoluble fiber. Similar microstructural images were taken in the studies of Martínez et al. (2014) and Rosell et al. (2009). Sangnark and Nookhorm (2003) found that a decrease in particle size of dietary fibers was associated with reduction in water holding capacity ($r^2 = 0.99$). As can be seen in Fig. 1 oat fiber had the smallest particle size than the other fibers so they had the lowest water holding capacity.

Rheology

The shear stress (τ) versus shear rate ($\dot{\gamma}$) data was fitted well to Power Law equation with a high coefficient of determination,

$$\tau = k (\dot{\gamma})^n$$

where, τ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), k is the consistency index ($Pa \cdot s^n$) and n is flow behavior index.

Flow curves of batter are shown in Fig. 2. All the formulations containing different fibers and control batter showed shear thinning behavior which indicated that apparent viscosity decreased with increase in shear rate.

Table 2 shows the effect of fiber type and concentration on batter rheological characteristics. Batter containing 10% lemon fiber had the lowest flow behavior index (n) and the highest consistency coefficient (k). The consistency of batters is a significant parameter that affect final product quality, especially loaf volume because it affects retention of small bubbles, which are initially incorporated into the dough during the mixing (Turabi et al. 2008). All batter formations containing fiber had higher consistency index than control batter. However, batter containing 5% oat and pea fiber showed similar rheological characteristics with control batter. Due to the higher water binding capacity of fiber, water absorption increases which reduces the amount of free water available to facilitate the movement of particles in batters and consequently gives high consistency index. Particle size was also effective on rheological properties. Dikeman and Fahey (2006) stated that reduction in particle size resulted in decreased viscosity. Therefore, lemon fiber which had the highest water binding capacity and higher particle size showed the higher consistency index as compared to the other fibers. Similar result was found by Lebesi and Tzia (2011) in which dietary fiber addition increased the consistency index. In this study, all fibers were composed of mostly insoluble fibers. Martínez et al. (2014) stated that the increase in dough consistency in the presence of fibers could be due to their effects on the internal structure of dough. By analyzing microstructure of dough containing insoluble fiber, it was concluded that insoluble fibers remained unchanged in dough and became more rounded by starch granules that formed irregular structures than control dough. Therefore, insoluble fibers increased consistency of bread dough. In addition, as the fiber concentration increased, the consistency coefficient increased, too (Table 2). Increasing amount of fiber resulted in an increase the water absorption capacity of batter due to the higher soluble dietary fiber (Turkut et al. 2016). Similar result was also obtained by Gómez et al. (2010).

An amplitude sweep test was conducted to determine the linear viscoelastic range. When applied strain is held below the limiting value, the structure of the sample is stable under this low deformation condition. At higher strains, due

Fig. 1 SEM images of fibers **a** pea, **b** oat, **c** lemon, **d** apple

to exceeding the limit of the linear viscoelastic range, the structure of sample is irreversibly destroyed (Hager et al. 2011). Regarding linear viscoelastic range, 0.1% strain rate was chosen for oscillatory test. Frequency sweep test was carried out and storage (G') and loss modulus (G'') values of cake batters are shown in Fig. 3a, b, respectively. In all samples, both G' and G'' values increased with angular frequency. Storage modulus was found to be higher than loss modulus which indicated a solid like behavior of batters. As can be seen in Fig. 3a, b, all cake batters containing fibers had higher storage and loss modulus than control one. Fiber addition had significant effect on viscoelastic properties of batter. It is well known that both moduli are very sensitive to water content. As the water content of dough decreases, modulus increases (Peressini and Sensidoni 2009). Figure 3a, b shows that as fiber content increased both moduli increased. Fibers having high water binding capacity could bind more water so water availability decreased. Similarly, Singh et al. (2016) examined that addition of dietary fiber of black carrot pomace increased the batter moduli of gluten free batter due to the reduced amount of free water available to facilitate the movement of particles in batters. The

difference between modulus of batters resulted from the difference between water holding capacity of fibers (Gómez et al. 2010). Lemon fiber had the highest water holding capacity. Therefore, available water was lower which resulted an increase in dynamic moduli. Batter containing 5% oat and pea fibers had similar modulus values with control batter.

Specific volume

The effect of the fiber supplementation on specific volume of cakes is shown in Table 3. Most of the cakes containing fibers had lower specific volume than control one. Specific volume of cakes depends on the nature and the amount of added fibers. Fibers may interfere with gluten network formation and dilute functional gluten proteins (Pomeranz et al. 1977). They disorganized the starch–gluten matrix and led to a decrease in the gas retention capacity. Thus, cakes with low volume were obtained. Related to this reason, as the fiber concentration increased, the specific volume of cakes decreased. In addition, cake batter consistency is an important parameter that affects the product volume because it is related to the capacity of gas retention.

Fig. 2 Flow curves of cake batters containing different types and amounts of dietary fiber, filled circle 5% pea, filled triangle 5% oat, filled diamond 5% apple, filled square 5% lemon, open circle 10% pea, open triangle 10% oat, open diamond 10% apple, open square 10% lemon, asterisk control

Table 2 Power law model constants for cake batter with different formulations

Batter formulation	k (Pa s ⁿ)	n	r^2
Control	38.677 ± 1.483^f	0.596 ± 0.005^a	0.999
5% pea fiber	57.697 ± 2.283^e	0.567 ± 0.007^{ab}	0.987
5% oat fiber	53.990 ± 3.311^e	0.569 ± 0.004^{ab}	0.986
5% apple fiber	74.670 ± 2.010^d	0.524 ± 0.009^{bc}	0.991
5% lemon fiber	149.75 ± 5.050^b	0.455 ± 0.004^d	0.992
10% pea fiber	77.060 ± 3.592^d	0.552 ± 0.004^{bc}	0.992
10% oat fiber	84.067 ± 3.070^d	0.530 ± 0.001^{bc}	0.992
10% apple fiber	114.567 ± 1.377^c	0.524 ± 0.018^c	0.984
10% lemon fiber	604.064 ± 2.050^a	0.304 ± 0.004^e	0.934

Columns having different letters are significantly different ($p \leq 0.05$). k consistency index (Pa sⁿ) and n : flow behavior index

Some researchers claimed that as the consistency increased, the rising rate of bubbles in cake decreased. Therefore, more air bubbles were retained in cakes and cakes having higher volume were obtained (Lebesi and Tzia 2011). In low consistency cake batter, rapidly rising bubbles resulted in low volume (Lee et al. 2005). On the contrary, high batter consistency prevented expansion of cakes that leads to lower specific volume (Gularte et al. 2012). This shows that there may be an optimum consistency to achieve cakes with high volume. In this study, it

was found that adding fiber increased the batter consistency (Table 2). A significant correlation between consistency index and specific volume ($r = -0.954$, $p = 0.000$) was observed. As the batter consistency index increased, cakes having lower specific volume were obtained. There was significant difference between cakes enriched with different type of fibers ($p \leq 0.05$). Oat and pea had higher amount of insoluble fiber than apple and lemon. Therefore, consistency index of batter containing lemon and apple was higher (Table 2). Especially lemon fiber resulted in the highest consistency index of batter and the lowest specific volume of cakes. In the study of Gómez et al. (2003), it was stated that the lowest specific volume of bread was obtained when coffee fiber with higher soluble fiber content was added to bread formulation. In addition, higher elastic and viscous modulus values inhibited cake structure development leading to lower volume (Gómez et al. 2010). This confirmed the lowest specific volume of lemon fiber containing cakes. A reduction of specific volume due to fiber addition was previously examined by many researchers. Fu et al. (2015) studied the effect of addition lemon fiber on the quality of Mantou (steamed bread). It was stated that as the lemon fiber concentration increased, specific volume of breads decreased due to the disruption of gluten network. Similarly, Chang et al. (2015) found that lemon fiber enriched breads had lower specific volume than

Fig. 3 Variation of elastic properties with frequency for cake batters containing different fiber types and concentrations, filled circle 5% pea, filled triangle 5% oat, filled diamond 5% apple, filled square 5% lemon, open circle 10% pea, open triangle 10% oat, open diamond 10% apple, open square 10% lemon, asterisk control. **a** Storage modulus (G'). **b** Loss modulus (G'')

bread with no fiber. Collar et al. (2009) used cocoa shell as a fiber source to produce bread and a decrease in specific volume was observed. Sudha et al. (2007) observed a decrease in volume of cakes when concentration of apple pomace increased. However, specific volumes of cakes containing pea and oat with 5% concentration were not significantly different from control cakes and this is probably due to the low quantity of added fibers ($p > 0.05$). Thus, by adding pea and oat fibers with 5% concentration, functional cakes having similar volume were obtained.

Hardness

Texture is critical to consumer acceptance of baked products. The effect of different fibers and their concentrations on hardness value of cakes is shown in Table 3. According to ANOVA results, it was observed that fiber type affected hardness of cakes significantly ($p \leq 0.05$). As the fiber content increased, the hardness of cakes increased. In several studies, a negative correlation was found between specific volume and hardness (Sabanis et al. 2009; Lebesi and Tzia 2011). This study also confirmed the inverse

Table 3 Physical characteristics of cakes containing different formulations

Cake formulation	Hardness (N)	Specific volume (ml/g)	Weight loss (%)	Crust color change (ΔE^*)
Control	1.31 ± 0.03^c	1.91 ± 0.01^a	5.35 ± 0.16^a	31.86 ± 0.49^b
5% pea fiber	1.46 ± 0.04^c	1.87 ± 0.01^a	4.97 ± 0.13^{ab}	31.29 ± 0.92^{bc}
5% oat fiber	1.37 ± 0.05^c	1.86 ± 0.01^a	4.91 ± 0.12^{ab}	28.35 ± 1.25^{bcd}
5% apple fiber	1.65 ± 0.05^{de}	1.78 ± 0.02^b	4.74 ± 0.16^{ab}	44.72 ± 2.04^a
5% lemon fiber	2.21 ± 0.12^a	1.73 ± 0.02^{bc}	4.66 ± 0.11^{ab}	26.95 ± 0.19^d
10% pea fiber	2.24 ± 0.05^c	1.77 ± 0.01^b	4.72 ± 0.18^{ab}	31.74 ± 0.17^{bc}
10% oat fiber	2.06 ± 0.14^{cd}	1.79 ± 0.01^b	4.84 ± 0.19^{ab}	28.54 ± 0.01^{bcd}
10% apple fiber	3.02 ± 0.09^b	1.60 ± 0.04^c	4.63 ± 0.12^{ab}	48.05 ± 0.26^a
10% lemon fiber	3.82 ± 0.12^c	1.32 ± 0.01^d	4.50 ± 0.17^b	28.68 ± 0.51^{cd}

Columns having different letters are significantly different ($p \leq 0.05$)

relationship between volume and hardness ($r = -0.944$, $p = 0.000$). Cakes having lower specific volume had higher hardness value. The reason could be related to the quantity of air retained by dough (Gómez et al. 2010). Smaller cakes were denser and had packed crumb structure which resulted in harder cakes (Sabanis et al. 2009). In addition, cakes enriched with lemon fiber had the lowest specific volume and the highest hardness value. Among fibers, lemon fiber had the highest water binding capacity. When the fiber with high water binding capacity was used, wheat flour could not absorb enough water to develop of gluten–protein network and rigid structure occurred (Chang et al. 2015). Similarly, in the study of Barak et al. (2014), it was found that as the alkaline water retention capacity increased, the hardness values of cookies increased, too. Therefore, more than 10% concentration of lemon and apple fiber caused a significant increase in hardness of cakes ($p \leq 0.05$). These results were also correlated with rheological properties of cake batter. Batter having higher consistency index could not hold air bubbles which resulted in harder cake structure. The results shown in Table 3 were comparable to those in the studies of Wu et al. (2012) who reported that breads containing higher concentration of fiber had higher hardness value. Similarly Gómez et al. (2010) stated that wheat fiber gave the highest batter viscosity but the highest hardness value. The adverse effects of fibers on texture was observed by many other authors (Abdul-Hamid and Luan 2000; Gualarte et al. 2012; Martínez et al. 2014). However, cakes containing pea and oat fibers at a concentration of 5% had similar hardness value with control cakes. This was an expected result because these cakes also had similar specific volume with control cakes. Belghith Fendri et al. (2016) also found that breads containing fibers from pea and broad bean pod had similar specific volume and hardness value with control breads containing no fiber. Therefore, addition of 5% pea and oat

fibers is advantageous to obtain dietary fiber containing cakes.

Weight loss

Table 3 shows the effects of fibers on weight loss of cakes during baking. Generally, the weight loss of the cakes is in direct relation with the water loss. No significant difference ($p > 0.05$) was observed between control and cakes containing pea, oat and apple fiber. However, the weight loss of cakes enriched with 10% lemon fiber was significantly less than control ($p \leq 0.05$). Among these fibers, the water holding capacity of lemon fiber was found to be the highest. Therefore, higher amount of lemon fiber prevented moisture loss of cakes as compared to control cake. Collar et al. (2009) used cocoa which was soluble fiber to enrich breads and stated that as the concentration of fiber increased, moisture content of breads increased, too. This means, weight loss of breads can be decreased by adding more soluble fiber. Fibers have similar effect on weight loss with gums. Seyhun et al. (2005) stated that gums are used to increase moisture retention in baking products. It was found that guar and xanthan gum were the most effective gum for preventing moisture loss because they had higher water binding capacity.

Color

The effect of different fiber addition on the cake crust color was summarized in Table 3. In general, color of baked products depends on physicochemical characteristic of the dough (water content, pH, reducing sugars and amino acid content), baking time and temperature (Esteller and Lannes 2008). The color difference, ΔE^* was used to show the influence of fiber additions. According to statistical analysis, there was no significant difference between the crust

color of cakes having different concentration of fibers ($p > 0.05$). The color of crust is mainly associated with Maillard and caramelization reactions. However, incorporation of insoluble fibers did not alter the quantity of sugars and amino acids (Martínez et al. 2014). There was significant difference between crust color of cakes containing apple and lemon fibers and control cake ($p \leq 0.05$). This fact could be due to the original colors of apple and lemon fiber. Gómez et al. (2003) examined the effects of different fibers on crust color and did not find any significant difference in the crust color of cakes containing fibers (orange, pea, wheat and cellulose) and control cake ($p > 0.05$). However, when cocoa and coffee fibers were used, cakes with lower lightness were obtained due to the original color of these fibers. Because of the same reason, Bchir et al. (2014) found breads enriched with date fiber had a darker color than control cake.

Microstructure

The influence of fibers on cake microstructure was investigated by scanning electron microscope. The images of cakes containing 10% fiber and control cake are shown in Fig. 4. In general, high specific volume is a remark of more porous structure for baked products. The images of cakes could be correlated with specific volume of cakes. As can be seen in Fig. 4, control cake had more porous structure than fiber enriched cakes. This could be confirmed with results of the specific volume in which control cakes had higher specific volume than cakes containing fiber. Similarly, Polaki et al. (2010) stated that breads containing fiber had less porous structure than control breads due to the gluten dilution effect of fibers. When the effect of different fiber on volume was examined, especially lemon and apple fiber caused significant reduction in cake volume

Fig. 4 SEM images of fiber (10%) enriched cakes **a** pea, **b** oat, **c** lemon, **d** apple, **e** control

($p \leq 0.05$). Figure 4c, d showed that lemon and apple fiber containing crumbs had small gas cells representing a dense structure. Oat and pea fiber enriched crumbs had high number and larger air cells exhibiting more aerated structure as compared to lemon and apple containing cakes. This result was supported by specific volume results (Table 3). Tudorica et al. (2002) compared the effects of different fibers (pea and inulin) on microstructure of raw and cooked pasta. It was stated that the addition of pea fiber (mostly insoluble fiber) disrupted the continuity of the protein matrix and inulin fiber (soluble fiber) containing pasta had more continuous protein–fiber–starch matrix. Therefore, fiber containing pasta had more porous structure than pasta containing inulin. In this study, although all fibers used in this study were mainly composed of insoluble fiber, the amount of soluble fiber was higher in lemon and apple fiber. Therefore, oat and pea fiber gave less rigid and more porous structure. These results were also consistent with hardness value of cakes. Cakes with more aerated structure had lower hardness value so the hardness of oat and pea fiber cakes was lower than the others (Table 3).

Conclusion

Addition of fibers affected rheological properties in a way that it increased consistency index, storage and loss modulus. Lemon fiber containing batters were the most viscous ones. Rheological properties of cake batters were found to be correlated with volume and texture of cakes. Cakes containing 5% pea and 5% oat fibers had similar specific volume and texture with control cake. As the fiber content increased, specific volume of cakes decreased but hardness increased. Cakes containing 10% lemon fiber showed lower weight loss than the other cakes. Due to the original color, apple and lemon fiber resulted in significant color difference. Microstructural analysis supported the results of specific volume and hardness. When the images of cakes containing 10% fiber were investigated, it was observed that fiber addition decreased porosity of cakes. In addition, oat and pea fiber containing cakes had more porous structure as compared to lemon and apple ones. On the basis of obtained results, addition of oat and pea fiber with 5% could be an effective way to increase dietary fiber content of cakes without affecting physical properties adversely.

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