Effects of beta-glucan addition on the physicochemical and microbiological characteristics of fermented sausage

Bilal Yuca¹ · İbrahim Topçu¹ · Hatice Yağcılar-Aydemir¹ · Cem Okan Özer² · Birol Kılıç¹ · Gülden Başyigit-Kılıç³

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Abstract The objective of this study was to investigate the effects of added beta-glucan (β -glucan) levels on the lipid oxidation, physicochemical, microbiological, textural and sensorial properties of fermented sausage produced with various amounts of beef fat during fermentation and storage periods. To determine the effects of β -glucan, twelve sausage treatments included four controls (no β -glucan) with or without beef fat and starter culture addition and eight β -glucan incorporated groups produced with addition of starter culture, various levels of β -glucan (0, 1, 2%) and different levels (0, 10, 15, 20%) of beef fat were manufactured. The results indicated that addition of β -glucan decreased thiobarbituric acid reactive substances (TBARS) values compared to control groups which had 20% beef fat ($P < 0.05$). β -glucan enhanced the growth of lactic acid bacteria during fermentation and storage periods ($P < 0.05$). The addition of β -glucan caused a decrease in water activity and pH values of sausage during the fermentation and storage ($P < 0.05$). Color values, fatty acid composition, protein, fat, moisture and ash content were not influenced by the use of β -glucan ($P < 0.05$). Higher levels of β -glucan in sausage formulation caused an increase in the hardness values of sausage ($P < 0.05$).

Keywords Sausage · Beta-glucan · Meat fermentation · Lipid oxidation · Texture

Introduction

Many studies have indicated that a high animal fat diet may increase the risk of many diseases such as colon cancer, cardiovascular disease and obesity (Larsson et al. 2005). Therefore, the researcher has suggested that consumption of low-fat foods or high intake of dietary fibers may be protective against these diseases. In this respect, to reduce saturated fat content, meat product formulations have been modified by replacing animal fats with various substances such as some carbohydrates and fibers. However, these changes in meat product formulations can lead to a product with poor textural and sensorial quality characteristics (Hygreeva et al. 2014; Pinero et al. 2008; Rather et al. 2015; Vandendriessche 2008). Therefore, it is important to search for alternative sources that can be used in meat products manufacturing to produce healthy meat products with good quality properties. In this regard, beta-glucan (β -glucan), a water-soluble fiber may be incorporated into meat product formulation to both replace animal fat and get beneficial health effects in the human body.

β -glucan has an important role in human nutrition. It provides positive effects on hypertension, total and low-density lipoprotein contents, blood glucose, insulin level and gastrointestinal health (Kilic and Akpinar 2013; Wood 2007). Therefore, The US Food and Drug Administration (FDA) has suggested 3 g or more oat's β -glucan intake per day to get health benefits.

Previous studies have indicated that fibers can be used as functional ingredients during food manufacturing due to their thickening, stabilizing and gelling properties as well

✉ Cem Okan Özer
cemokanozer@nevsehir.edu.tr; cemokanozer@gmail.com

¹ Department of Food Engineering, Engineering Faculty, Suleyman Demirel University, Isparta, Turkey

² Department of Food Engineering, Engineering and Architecture Faculty, Nevsehir Hacı Bektaş Veli University, 50300 Nevşehir, Turkey

³ Department of Food Engineering, Engineering and Architecture Faculty, Mehmet Akif Ersoy University, Burdur, Turkey

as their prebiotic characteristics (Aleson-Carbonell et al. 2005; Laroche and Michaud 2007). In additions, some studies have reported that use of β -glucan, which is a prebiotic, in some fermented food formulation increases the number of some microorganisms in the flora such as *L. Plantarum*, *L. Acidophilus* and *L. Casei* strains which play important roles in the fermentation process in meat products (Kilic and Akpinar 2013; Thammakiti et al. 2004). There are a few studies about using of β -glucan in several meat products such as hamburgers, sausages and meatballs which have reported improvements in cooking yield and textural properties (Alvarez and Barbut 2013; Morin et al. 2002; Pinero et al. 2008). However, there is a lack of information about the effects of β -glucan addition in meat product manufacturing during fermentation. Therefore, the present study is aimed to assess the effect of oat's β -glucan as an animal fat replacer on lipid oxidation, physicochemical, microbiological, textural and sensorial properties of dry fermented sausage during fermentation and storage periods.

Material and methods

Materials

Boneless beef cuts (*Longissimus thoracis etlumborum*) at 24 h post-mortem and beef fat were purchased from local meat products factory (Gülköy Meat Plants, Isparta, Turkey) for each of three replications on separate production days. All subcutaneous and intermuscular fats were removed from the muscles. The low-fat meat and beef fat were separately ground in a 2 mm and 3 mm plate meat grinder (Arı Makine A.Ş., İstanbul, Turkey), respectively. The commercial β -glucan, which is produced from oat (70% oat beta-glucan, PROMOAT soluble oat fiber), was provided by Güler Kimya Ltd. Şti (Istanbul, Turkey). The freeze-dried culture mix containing *Lactobacillus curvatus*, *Staphylococcus xylosus*, *Staphylococcus carnosus* and *Pediococcus pentosaceus* was used as starter culture.

Sausage preparation

The production and ripening of dry fermented sausage were carried out as described in Ozer and Kilic (2014). As shown in Table 1, the experimental design consisted of four controls and eight treatment groups. The two positive control groups incorporated with 20% beef fat were prepared without the addition of starter culture (PC1) and with starter culture (PC2). In addition, two negative control groups without starter culture (NC1) and with the starter culture (NC2) were also manufactured without beef fat addition. Positive and negative controls were not

Table 1 Experimental design used in sausage manufacture

Groups	Beef fat (%)	β -Glucan (%)	Starter culture
PC1	20	0	–
PC2	20	0	+
NC1	0	0	–
NC2	0	0	+
1	20	1	+
2	20	2	+
3	15	1	+
4	15	2	+
5	10	1	+
6	10	2	+
7	0	1	+
8	0	2	+

PC positive control, NC negative control, + with starter culture, – without starter culture

formulated with β -glucan. The remaining eight treatment groups were prepared with the addition of different ratios of animal fat and β -glucan as shown in Table 1. The starter culture mixture was added during the mixing stage at a dose of 10^8 cfu/kg of sausage dough. After 7 days of fermentation period, sausages were vacuum packed in a polyethylene polyamide plastic bags and stored at 4 °C for 30 days. The sausage manufacturing process was carried out three times on separate production days.

Physicochemical composition

Protein, moisture, ash and fat content analysis of samples were carried out according to analysis procedures of AOAC (2000). pH of samples was determined using pH meter (Orion Model 420, Boston, USA). Water activity values of samples were determined out at room temperature by a water activity meter (Novasina TH200, Axair Ltd., Pfäffikon, Switzerland). Color measurements were made using a colorimeter (TCR 200 Color Reader, BAMR Ltd., Claremont, South Africa) according to Ozer and Kilic (2014).

TBARS analysis

Oxidative stability was evaluated by measuring the thio-barbituric acid reactive substances (TBARS). TBARS values of all fermented sausage treatment groups were determined according to Kilic and Richards (2003) method on the manufacturing day, at the end of fermentation and during the storage period. The TBARS values were expressed as μ mol TBARS per kg of meat.

Fatty acid composition analysis

Total lipids of samples were extracted by the method of Bligh and Dyer (1959). The extracted lipids were stored at -20°C . Heptadecanoic acid (Sigma-Aldrich Inc., Oakville, ON) as an internal standard was added to the samples after lipid extraction. Then, the fatty acids were methylated with the basic catalyst sodium methoxide (CH_3ONa) and the acid catalyst boron trifluoride-methanol reagent ($\text{BF}_3\text{-MeOH}$) as described by He et al. (2009). The fatty acid methyl esters (FAME) were analyzed on an Agilent 7820A gas chromatograph system (Agilent Technologies, USA) equipped with a flame ionization detector (FID) as described by Ozer and Kilic (2014). Fatty acid methyl esters were identified by comparing retention times with FAME standards (Sigma-Aldrich Inc., Oakville, ON) and reported as % of fatty acids.

Texture profile analysis (TPA)

Instrumental texture profile analysis (TPA) was performed by using a TA.XT2 Texture Analyzer (NY/Stable Micro Systems, Godalming, UK) and cohesiveness, hardness (g), springiness, gumminess, adhesiveness (g·s), resilience and chewiness values of the samples were determined. Samples were cut into cylinders (10 ± 0.5 mm in height), wrapped with stretch film and held at 4°C for 30 min before the TPA analysis. Conditions of texture analysis were as described by Ozer and Kilic (2014).

Sensory evaluation

The sensory evaluations of sausages were performed at Food Engineering Department at the Suleyman Demirel University by a group of twenty-two panelists (14 males and 8 females, between 21 and 29 years old), using procedures of the IFT (1981). Samples from each group were chosen randomly, presented in dishes coded with random three-digit numbers, reheated at microwave oven (40 s) and served to the panelists. The panelists evaluated the cross-sectional surface color and appearance, ease of fracture, odor, flavor, meat flavor intensity, firmness, juiciness and the overall acceptability of the sausages. Sausage attribute intensities were rated on 9-point scale.

Microbiological analysis

Sausage samples (10 g) were weighed aseptically, placed into the sterile peptone water (90 ml) and homogenized. Subsequent decimal dilutions of each sample was prepared in peptone water and 0.1 ml appropriate dilution of samples were spread on the following media; Plate Count Agar (Merck, Darmstadt, Germany) for total viable aerobic

count (TVAC), incubated at 30°C for 48 h; De Man, Rogosa and Sharpe Agar (Merck, Darmstadt, Germany) for lactic acid bacteria count, incubated in anaerobic jar at 37°C for 48 h; Potato Dextrose Agar (Merck, Darmstadt, Germany) for yeast and molds, incubated at 25°C for 72 h; Eosin Methylene Blue Agar (Merck, Darmstadt, Germany) for coliform, incubated at 37°C for 48 h.

Statistical analysis

A one-way completely randomized design was adopted for this study. The results were expressed as mean $\pm$ standard errors values from the three replications. SPSS 22.0.0 (SPSS Inc., Chicago, USA) statistical analysis software was used for statistical evaluation of the results. A completely randomized experiment was designed with 4 controls (2 positives and 2 negatives), 8 treatment groups and 3 replications. The data were analyzed using the general linear model (GLM) procedure, in which treatment groups and storage time were assigned as fixed effects and replications as a random effect. Experimental data were collected from chemical composition, physicochemical and microbiological analysis and generated data were analyzed by one-way analysis of variance (ANOVA). Duncan multiple comparison tests was used to compare the differences in mean values that were considered significant when $P < 0.05$.

Results and discussion

Physicochemical composition

The average ash, moisture, fat and protein contents of samples are presented in Table 2. Chemical composition results (except fat content) of sausage dough showed non-significant differences among all treatment groups. As expected, there were significant differences in the fat content of treatments ($P < 0.05$) due to variation in the amount of beef fat used in sausage manufacturing process. Similar differences were also determined after fermentation ($P < 0.05$). Furthermore, the results indicated that the use of starter culture and beef fat had an influence on the moisture content of samples after the fermentation period ($P < 0.05$). Using starter culture in sausage production generally decreased the moisture content of sausage samples at the end of the fermentation period ($P < 0.05$). A reduction in moisture content may be associated with a decreased meat pH which causes denaturation of muscle proteins, leading a decrease in the water-holding capacity. It was also previously reported that the use of starter cultures accelerates water loss and high-fat content decreases the drying rate in sausage (Bozkurt and Bayram 2006;

Table 2 Physicochemical composition of sausages

Groups	Protein (%)			Fat (%)			Ash (%)			Moisture (%)		
	Manufacturing day	End of 7 days fermentation		Manufacturing day	End of 7 days fermentation		Manufacturing day	End of 7 days fermentation		Manufacturing day	End of 7 days fermentation	
PC1	18.95 ± 0.15 ^{bcdB}	20.88 ± 0.14 ^{bcdA}		28.55 ± 0.55 ^{aB}	36.27 ± 0.37 ^{aA}		2.60 ± 0.05 ^{aB}	4.33 ± 0.22 ^{abcdA}		70.31 ± 0.46 ^{bA}	43.98 ± 0.16 ^{aB}	
PC2	19.29 ± 0.30 ^{abcdB}	21.21 ± 0.30 ^{abcdA}		28.14 ± 0.41 ^{aB}	35.43 ± 0.31 ^{bA}		2.82 ± 0.84 ^{aB}	3.83 ± 0.27 ^{cdeA}		71.47 ± 0.71 ^{abA}	41.60 ± 0.81 ^{bB}	
NC1	20.17 ± 0.34 ^{aB}	22.09 ± 0.34 ^{aA}		8.79 ± 0.30 ^{dB}	15.99 ± 0.30 ^{gA}		2.60 ± 0.13 ^{aB}	4.46 ± 0.05 ^{abcA}		73.24 ± 1.10 ^{aA}	41.61 ± 0.67 ^{bB}	
NC2	19.75 ± 0.31 ^{abB}	21.67 ± 0.31 ^{abA}		9.02 ± 0.41 ^{dB}	15.90 ± 0.17 ^{gA}		2.67 ± 0.36 ^{aB}	3.95 ± 0.79 ^{bcdA}		71.18 ± 1.62 ^{bA}	38.69 ± 1.18 ^{cB}	
1	18.66 ± 0.65 ^{bcdB}	20.58 ± 0.65 ^{bcdA}		27.83 ± 0.37 ^{aB}	35.51 ± 0.32 ^{bA}		2.82 ± 0.43 ^{aB}	3.34 ± 0.01 ^{efA}		69.84 ± 1.45 ^{bcA}	37.05 ± 0.42 ^{cdB}	
2	18.75 ± 0.58 ^{bcdB}	20.67 ± 0.58 ^{bcdA}		28.54 ± 0.26 ^{aB}	35.94 ± 0.09 ^{abA}		2.95 ± 0.06 ^{aB}	4.08 ± 0.14 ^{abcdeA}		71.39 ± 0.76 ^{abA}	41.51 ± 1.41 ^{bB}	
3	19.62 ± 0.70 ^{abcB}	21.54 ± 0.70 ^{abcA}		21.29 ± 0.86 ^{bB}	28.93 ± 0.24 ^{cA}		2.88 ± 0.24 ^{aB}	4.41 ± 0.02 ^{abcA}		70.13 ± 0.31 ^{bA}	41.27 ± 0.65 ^{bB}	
4	18.43 ± 0.57 ^{dB}	20.35 ± 0.57 ^{dA}		21.51 ± 0.37 ^{bB}	27.93 ± 0.26 ^{dA}		2.84 ± 0.62 ^{aB}	4.75 ± 0.40 ^{abA}		71.06 ± 0.65 ^{bA}	41.21 ± 0.70 ^{bB}	
5	18.57 ± 0.18 ^{cdB}	20.49 ± 0.18 ^{cdA}		16.99 ± 0.30 ^{cB}	22.00 ± 0.20 ^{eA}		2.91 ± 0.43 ^{aB}	4.82 ± 0.06 ^{aA}		68.13 ± 0.14 ^{cdA}	38.24 ± 1.48 ^{cdB}	
6	18.88 ± 0.34 ^{bcdB}	20.80 ± 0.34 ^{bcdA}		17.21 ± 1.08 ^{cB}	21.11 ± 0.18 ^{fA}		2.53 ± 0.33 ^{aB}	3.57 ± 0.49 ^{deA}		67.52 ± 0.37 ^{dA}	34.19 ± 0.68 ^{dB}	
7	19.70 ± 0.54 ^{abB}	21.62 ± 0.54 ^{abA}		8.56 ± 0.55 ^{dB}	15.37 ± 0.14 ^{ghA}		2.76 ± 0.05 ^{aB}	2.78 ± 0.44 ^{fA}		66.59 ± 0.32 ^{dA}	36.65 ± 1.54 ^{cdB}	
8	19.17 ± 0.04 ^{abcdB}	21.09 ± 0.04 ^{abcdA}		8.79 ± 0.31 ^{dB}	15.10 ± 0.45 ^{hA}		2.78 ± 0.92 ^{aB}	3.93 ± 0.05 ^{bcdA}		66.24 ± 1.04 ^{dA}	36.11 ± 0.96 ^{deB}	

All values are the mean ± standard error of three replicates

a, b, c (↓) Different letters within a column are significantly different ($P < 0.05$)

A,B (→) Different letters within a row are significantly different ($P < 0.05$)

Gökalp 1995). However, the addition of β -glucan did not affect protein, fat, moisture and ash contents of the samples.

Average pH value for all treatment groups in sausage dough was around 5.71 (Table 3) and a significant reduction in pH values in all sausage groups was determined during the fermentation period ($P < 0.05$). The addition of β -glucan and using starter culture in sausage manufacturing led to the accelerated pH decline during the fermentation period ($P < 0.05$). While the lowest pH value among all treatment groups was determined in sausages containing β -glucan, the highest pH value was obtained in all positive and negative control groups which were not incorporated with β -glucan ($P < 0.05$). pH of all treatment groups were quite stable during storage time. The reason for the enhanced pH decrease in β -glucan containing groups may

be related to the production of lactic acid as a result of β -glucan consumption by lactic acid bacteria (Bozkurt and Erkmen 2002; Lucke 1994). pH values and chemical composition of sausage samples in the present study were consistent with the values reported by Turkish standards and previous studies (Bozkurt and Bayram 2006; Bozkurt and Erkmen 2002; TSE 2002).

The results of water activity (data is not presented) indicated that the addition of β -glucan in sausage manufacturing resulted in a decrease in the water activity ($P < 0.05$). At the end of fermentation, the highest and the lowest water activity values were determined in PC1 and group 8, respectively compared with other groups ($P < 0.05$). Results showed that water activity values of sausages decreased with increasing the amount of added β -glucan ($P < 0.05$). This results may be associated with the

Table 3 TBARS and pH values of sausages at the end of the fermentation and storage periods ($\mu\text{mol/kg}$)

Groups	Sausage dough	Sausage at the end of 7 days fermentation	Storage (+ 4 °C)			
			Day 5	Day 10	Day 15	Day 30
TBARS						
PC1	0.62 ± 0.04 ^{aE}	4.89 ± 0.13 ^{aD}	5.40 ± 0.11 ^{aC}	5.99 ± 0.13 ^{aB}	6.16 ± 0.06 ^{aAB}	6.36 ± 0.14 ^{aA}
PC2	0.66 ± 0.09 ^{aE}	3.91 ± 0.06 ^{bD}	4.30 ± 0.07 ^{bC}	4.77 ± 0.07 ^{bB}	4.89 ± 0.04 ^{bB}	5.07 ± 0.08 ^{bA}
NC1	0.69 ± 0.04 ^{aD}	3.34 ± 0.02 ^{defC}	3.43 ± 0.04 ^{ghB}	3.48 ± 0.01 ^{gB}	3.51 ± 0.04 ^{hB}	3.73 ± 0.05 ^{hA}
NC2	0.91 ± 0.12 ^{aD}	3.17 ± 0.06 ^{fghiC}	3.35 ± 0.04 ^{hiB}	3.38 ± 0.02 ^{gB}	3.46 ± 0.02 ^{hiB}	3.57 ± 0.04 ^{iA}
1	0.74 ± 0.12 ^{aD}	3.56 ± 0.03 ^{cC}	3.87 ± 0.06 ^{cC}	4.30 ± 0.07 ^{cB}	4.39 ± 0.06 ^{cB}	4.56 ± 0.07 ^{cA}
2	0.89 ± 0.12 ^{aE}	3.46 ± 0.01 ^{cdD}	3.76 ± 0.02 ^{cdC}	4.18 ± 0.02 ^{cdB}	4.21 ± 0.04 ^{dB}	4.43 ± 0.02 ^{cdA}
3	0.84 ± 0.15 ^{aF}	3.39 ± 0.01 ^{cdeE}	3.73 ± 0.02 ^{deD}	4.14 ± 0.02 ^{dC}	4.23 ± 0.02 ^{dB}	4.40 ± 0.02 ^{deA}
4	0.78 ± 0.31 ^{aE}	3.31 ± 0.03 ^{defgD}	3.62 ± 0.01 ^{efC}	4.01 ± 0.02 ^{eB}	4.09 ± 0.02 ^{eB}	4.26 ± 0.01 ^{efA}
5	0.62 ± 0.14 ^{aE}	3.22 ± 0.06 ^{efghD}	3.52 ± 0.06 ^{fgC}	3.91 ± 0.06 ^{efB}	3.99 ± 0.07 ^{fB}	4.15 ± 0.07 ^{fgA}
6	0.85 ± 0.17 ^{aF}	3.16 ± 0.15 ^{ghiE}	3.41 ± 0.02 ^{ghD}	3.79 ± 0.02 ^{fC}	3.86 ± 0.03 ^{gB}	4.01 ± 0.03 ^{gA}
7	0.71 ± 0.16 ^{aE}	3.12 ± 0.09 ^{hiD}	3.25 ± 0.04 ^{ijC}	3.28 ± 0.02 ^{hiC}	3.36 ± 0.01 ^{ijB}	3.47 ± 0.07 ^{ijA}
8	0.67 ± 0.08 ^{aE}	3.03 ± 0.01 ^{iD}	3.16 ± 0.02 ^{iC}	3.25 ± 0.05 ^{iB}	3.28 ± 0.06 ^{iB}	3.42 ± 0.01 ^{jA}
pH						
PC1	5.70 ± 0.02 ^{bcdA}	5.05 ± 0.07 ^{aB}	5.03 ± 0.01 ^{aB}	5.01 ± 0.01 ^{aB}	5.00 ± 0.02 ^{aB}	5.07 ± 0.03 ^{aB}
PC2	5.71 ± 0.02 ^{abcdA}	4.85 ± 0.03 ^{bcB}	4.83 ± 0.03 ^{cB}	4.82 ± 0.03 ^{cdB}	4.78 ± 0.02 ^{cdB}	4.82 ± 0.02 ^{cB}
NC1	5.73 ± 0.01 ^{abcA}	4.92 ± 0.04 ^{bB}	4.96 ± 0.07 ^{bB}	4.95 ± 0.02 ^{bB}	4.90 ± 0.07 ^{bB}	4.92 ± 0.07 ^{bB}
NC2	5.73 ± 0.01 ^{abcA}	4.83 ± 0.02 ^{cB}	4.84 ± 0.07 ^{cB}	4.83 ± 0.02 ^{cB}	4.81 ± 0.02 ^{cB}	4.79 ± 0.06 ^{cB}
1	5.72 ± 0.01 ^{abcdA}	4.66 ± 0.01 ^{efB}	4.69 ± 0.01 ^{dB}	4.77 ± 0.03 ^{deB}	4.75 ± 0.01 ^{dB}	4.81 ± 0.05 ^{eB}
2	5.68 ± 0.01 ^{dA}	4.53 ± 0.01 ^{gB}	4.56 ± 0.01 ^{gB}	4.54 ± 0.01 ^{hB}	4.51 ± 0.07 ^{gB}	4.56 ± 0.07 ^{fB}
3	5.69 ± 0.01 ^{cdA}	4.59 ± 0.02 ^{fgB}	4.60 ± 0.04 ^{efB}	4.59 ± 0.02 ^{ghB}	4.61 ± 0.06 ^{fB}	4.65 ± 0.03 ^{deB}
4	5.71 ± 0.02 ^{abcdA}	4.64 ± 0.03 ^{efB}	4.59 ± 0.01 ^{fgB}	4.54 ± 0.03 ^{hB}	4.53 ± 0.01 ^{gB}	4.56 ± 0.03 ^{fB}
5	5.70 ± 0.02 ^{bcdA}	4.74 ± 0.01 ^{dB}	4.70 ± 0.01 ^{dB}	4.73 ± 0.03 ^{eB}	4.68 ± 0.02 ^{eB}	4.69 ± 0.03 ^{dB}
6	5.71 ± 0.02 ^{abcdA}	4.61 ± 0.01 ^{fB}	4.62 ± 0.01 ^{efB}	4.66 ± 0.01 ^{fB}	4.65 ± 0.04 ^{efB}	4.63 ± 0.02 ^{deB}
7	5.74 ± 0.01 ^{abA}	4.71 ± 0.01 ^{deB}	4.72 ± 0.02 ^{dB}	4.63 ± 0.02 ^{fgB}	4.64 ± 0.01 ^{efB}	4.66 ± 0.04 ^{deB}
8	5.75 ± 0.01 ^{aA}	4.60 ± 0.01 ^{fgB}	4.63 ± 0.07 ^{eB}	4.62 ± 0.01 ^{fgB}	4.64 ± 0.02 ^{efB}	4.61 ± 0.07 ^{fB}

All values are the mean $\pm$ standard error of three replicates

a, b, c ($\downarrow$) Different letters within a column are significantly different ($P < 0.05$)

A-F ($\rightarrow$) Different letters within a row are significantly different ($P < 0.05$)

hydrocolloid property of β -glucan that enhances the water holding capacity (Pinero et al. 2008).

The results of the present study revealed that the use of β -glucan and animal fat in different amounts did not influence L^* , a^* and b^* values of all groups during the fermentation and storage periods (data is not presented). This result is in agreement with Alvarez and Barbut (2013). On the other hand, an increase in L^* , a^* and b^* values due to β -glucan incorporation was reported by other researchers (Morin et al. 2002; Pereira et al. 2011; Sarteshniz et al. 2015). In general, L^* , a^* and b^* color values of all treatments decreased during fermentation and storage periods ($P < 0.05$). Reduction in all color values after the fermentation time was thought to be the results of oxidation development and changes in water content and pH values of sausages. The physicochemical properties of sausage manufactured in the present study were similar to the findings of previous studies (Bozkurt and Bayram 2006; Bozkurt and Erkmen 2002; Dalmis and Soyer 2008; Ozer and Kilic 2014).

TBARS analysis

There was no difference in TBARS values among all treatment groups at manufacturing day (Table 3). However, TBARS values of all sausage samples gradually increased during fermentation and storage periods ($P < 0.05$). Moreover, higher TBARS values were determined in PC1 and PC2 groups compared to other treatments at the end of fermentation and this difference was also evident during storage periods ($P < 0.05$).

According to TBARS results, it was determined that the use of starter culture in sausage containing beef fat significantly decreased TBARS values ($P < 0.05$). As far as the same level (20%) of beef fat-containing groups (PC1 and PC2) are taken into account, the PC2 group incorporated with starter culture had almost 20% lower TBARS values than PC1 which was produced without starter culture. Furthermore, the addition of β -glucan in sausage formulation resulted in a significant decrease in TBARS at the end of 7 days fermentation period ($P < 0.05$). For instance, a 10% reduction in TBARS formation was obtained in sausage groups formulated with β -glucan and 20% beef fat (Group 1 and 2) compared to control (PC2) group ($P < 0.05$). Bozkurt and Erkmen (2002) indicated that starter cultures producing catalase enzyme breakdown rancid compounds such as peroxides, aldehydes and ketones and therefore, sausages produced with starter culture had lower TBARS values than those made without starter culture. Therefore, it can be considered that the addition of β -glucan in sausage formulation might contribute to a decrease in TBARS values by promoting the

Table 4 Fatty acid composition of sausages at the end of fermentation

Fatty acids (%)	PC1	PC2	NC1	NC2	1	2	3	4	5	6	7	8
C14:0	1.18 ± 0.02 ^{bc}	1.23 ± 0.01 ^b	1.27 ± 0.03 ^{ab}	1.32 ± 0.07 ^a	1.23 ± 0.06 ^b	1.29 ± 0.01 ^{ab}	1.27 ± 0.02 ^{ab}	1.21 ± 0.01 ^b	1.29 ± 0.02 ^{ab}	1.33 ± 0.02 ^{ab}	1.27 ± 0.01 ^{ab}	1.34 ± 0.02 ^a
C14:1	0.29 ± 0.01 ^a	0.26 ± 0.02 ^a	0.26 ± 0.03 ^a	0.27 ± 0.01 ^a	0.23 ± 0.06 ^a	0.28 ± 0.01 ^a	0.29 ± 0.02 ^a	0.28 ± 0.01 ^a	0.26 ± 0.02 ^a	0.24 ± 0.02 ^a	0.25 ± 0.03 ^a	0.28 ± 0.01 ^a
C16:0	29.70 ± 0.02 ^a	29.75 ± 0.01 ^a	23.83 ± 0.01 ^{ef}	24.19 ± 0.01 ^e	29.37 ± 0.01 ^{ab}	29.36 ± 0.01 ^{ab}	27.53 ± 0.01 ^c	27.46 ± 0.01 ^c	25.22 ± 0.01 ^d	25.64 ± 0.01 ^d	24.37 ± 0.01 ^e	23.25 ± 0.01 ^{ef}
C16:1	1.26 ± 0.03 ^a	1.27 ± 0.02 ^a	0.93 ± 0.05 ^c	0.90 ± 0.02 ^c	1.19 ± 0.06 ^{ab}	1.17 ± 0.03 ^{ab}	1.12 ± 0.04 ^b	1.11 ± 0.01 ^b	0.98 ± 0.02 ^c	1.01 ± 0.01 ^c	0.91 ± 0.03 ^c	0.89 ± 0.02 ^c
C18:0	29.99 ± 0.11 ^a	29.95 ± 0.07 ^a	28.38 ± 0.04 ^{bc}	28.99 ± 0.08 ^b	29.91 ± 0.06 ^a	29.36 ± 0.03 ^{ab}	29.14 ± 0.04 ^{ab}	29.26 ± 0.04 ^{ab}	29.71 ± 0.07 ^a	29.68 ± 0.04 ^a	29.26 ± 0.11 ^{ab}	29.40 ± 0.08 ^{ab}
C18:1	35.19 ± 0.07 ^{ab}	35.04 ± 0.09 ^b	34.69 ± 0.04 ^c	34.63 ± 0.06 ^c	35.38 ± 0.04 ^{ab}	35.77 ± 0.12 ^a	35.44 ± 0.17 ^{ab}	35.32 ± 0.05 ^{ab}	34.54 ± 0.06 ^c	34.40 ± 0.06 ^c	33.76 ± 0.10 ^d	33.07 ± 0.08 ^d
C18:2	1.28 ± 0.01 ^{ef}	1.31 ± 0.03 ^{ef}	7.04 ± 0.04 ^{ab}	6.36 ± 0.02 ^b	1.47 ± 0.07 ^e	1.58 ± 0.08 ^e	3.31 ± 0.09 ^d	3.34 ± 0.11 ^d	5.12 ± 0.08 ^e	5.02 ± 0.13 ^c	7.18 ± 0.12 ^{ab}	8.07 ± 0.17 ^a
C20:0	1.17 ± 0.03 ^e	1.19 ± 0.01 ^e	3.60 ± 0.02 ^a	3.33 ± 0.06 ^{ab}	1.23 ± 0.01 ^e	1.19 ± 0.02 ^e	1.90 ± 0.02 ^d	2.01 ± 0.02 ^d	2.87 ± 0.03 ^d	2.68 ± 0.01 ^c	3.00 ± 0.01 ^{ab}	3.70 ± 0.03 ^a
ΣMUFA	36.74 ± 0.09 ^{ab}	36.57 ± 0.12 ^{ab}	35.88 ± 0.09 ^b	35.80 ± 0.04 ^b	36.81 ± 0.19 ^{ab}	37.22 ± 0.23 ^a	36.85 ± 0.11 ^{ab}	36.71 ± 0.08 ^{ab}	35.79 ± 0.07 ^b	35.65 ± 0.11 ^b	34.92 ± 0.14 ^c	34.24 ± 0.17 ^c
ΣPUFA	1.28 ± 0.11 ^f	1.31 ± 0.09 ^f	7.04 ± 0.11 ^b	6.36 ± 0.14 ^c	1.47 ± 0.16 ^f	1.58 ± 0.13 ^f	3.31 ± 0.17 ^c	3.34 ± 0.17 ^c	5.12 ± 0.11 ^e	5.02 ± 0.10 ^d	7.48 ± 0.21 ^{ab}	8.07 ± 0.33 ^a
ΣSFA	62.04 ± 0.13 ^a	62.12 ± 0.03 ^a	57.08 ± 0.11 ^d	57.84 ± 0.17 ^d	61.74 ± 0.07 ^{ab}	61.20 ± 0.08 ^b	59.85 ± 0.06 ^c	59.95 ± 0.04 ^c	59.09 ± 0.08 ^c	59.33 ± 0.08 ^c	57.90 ± 0.09 ^d	57.69 ± 0.11 ^d

All values are the mean ± standard error of three replicates

a–f (→) Different letters within a row are significantly different ($P < 0.05$)

Table 5 Textural properties of sausages at the end of the fermentation period

Groups	Hardness <i>N</i>	Adhesiveness <i>N s</i>	Resilience	Cohesiveness	Springiness Index	Gumminess <i>N/cm2</i>	Chewiness Index
PC1	2.31 ± 0.31 ^f	0.50 ± 0.10 ^a	0.28 ± 0.01 ^b	0.29 ± 0.03 ^c	0.64 ± 0.14 ^d	0.54 ± 0.03 ^g	0.38 ± 0.04 ^f
PC2	3.41 ± 0.39 ^e	0.80 ± 0.10 ^a	0.03 ± 0.01 ^b	0.35 ± 0.04 ^{bc}	0.92 ± 0.14 ^{abc}	0.92 ± 0.10 ^{fg}	0.70 ± 0.14 ^{ef}
NC1	3.33 ± 0.15 ^e	0.73 ± 0.20 ^a	0.03 ± 0.01 ^{ab}	0.34 ± 0.46 ^{bc}	0.74 ± 0.05 ^{cd}	1.47 ± 0.43 ^{de}	1.25 ± 0.22 ^{cd}
NC2	3.53 ± 0.41 ^e	0.70 ± 0.26 ^a	0.06 ± 0.01 ^a	0.55 ± 0.78 ^{ab}	1.03 ± 0.18 ^a	2.03 ± 0.29 ^{abc}	2.09 ± 0.12 ^a
1	4.44 ± 0.23 ^d	0.83 ± 0.11 ^a	0.03 ± 0.01 ^b	0.61 ± 0.18 ^a	0.82 ± 0.05 ^{bcd}	2.11 ± 0.17 ^{ab}	1.28 ± 0.42 ^{cd}
2	5.63 ± 0.29 ^a	0.70 ± 0.26 ^a	0.05 ± 0.02 ^{ab}	0.46 ± 0.07 ^{abc}	1.02 ± 0.19 ^{ab}	1.77 ± 0.09 ^{bcd}	1.80 ± 0.20 ^{ab}
3	4.64 ± 0.46 ^c	0.66 ± 0.15 ^a	0.04 ± 0.02 ^{ab}	0.36 ± 0.07 ^{bc}	0.72 ± 0.07 ^{cd}	1.62 ± 0.28 ^{cde}	1.56 ± 0.43 ^{bc}
4	5.14 ± 0.38 ^{ab}	0.80 ± 0.10 ^a	0.02 ± 0.01 ^b	0.37 ± 0.05 ^{bc}	0.98 ± 0.08 ^{ab}	0.94 ± 0.20 ^{fg}	0.77 ± 0.17 ^{ef}
5	3.96 ± 0.36 ^e	0.80 ± 0.10 ^a	0.04 ± 0.02 ^{ab}	0.64 ± 0.13 ^a	0.83 ± 0.02 ^{abcd}	2.36 ± 0.31 ^a	1.60 ± 0.39 ^{bc}
6	4.71 ± 0.54 ^{bc}	0.70 ± 0.26 ^a	0.05 ± 0.02 ^{ab}	0.41 ± 0.07 ^{bc}	0.99 ± 0.03 ^{ab}	1.70 ± 0.17 ^{bcd}	1.70 ± 0.29 ^{abc}
7	4.96 ± 0.20 ^{bc}	0.63 ± 0.11 ^a	0.03 ± 0.02 ^{ab}	0.34 ± 0.08 ^{bc}	0.72 ± 0.07 ^{cd}	1.18 ± 0.34 ^{ef}	1.27 ± 0.13 ^{cd}
8	3.41 ± 0.20 ^e	0.80 ± 0.10 ^a	0.02 ± 0.01 ^b	0.53 ± 0.21 ^{ab}	1 ± 0.06 ^{ab}	1.61 ± 0.35 ^{cde}	0.95 ± 0.22 ^{de}

All values are the mean ± standard error of three replicates

a, b, c (↓) Different letters within a column are significantly different ($P < 0.05$)

growth of starter cultures that enhance more catalase enzyme production during the fermentation period. Marklinder (1997) reported that soluble β -glucans were degraded and used during fermentation by *Lactobacilli*. Furthermore, it has been previously reported that β -glucan has ability to inhibit lipid oxidation due to their phenolic content such as tannins (Omana et al. 2011). Phenolic compounds are able decrease the rate of the oxidation process by scavenging and stabilizing lipid radicals via donation of hydrogen atoms (Haghsheenas et al. 2015).

Fatty acid analysis

Fatty acid composition of sausage samples at the end of the fermentation period is presented in Table 4. The results revealed that the addition of β -glucan in sausage formulation did not cause any significant change in the fatty acid composition of sausage samples. However, the use of beef fat resulted in significant changes in fatty acid composition in the final product at the end of fermentation ($P < 0.05$). Increasing the amount of beef fat in sausage formulation resulted in an increase in palmitic, palmitoleic, and oleic acid levels and a reduction in linoleic and arachidic acid levels ($P < 0.05$). As expected, reduction in the amount of added beef fat in sausage formulation caused an increase in polyunsaturated fatty acid (PUFA) levels and a decrease in saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA) levels ($P < 0.05$).

Texture profile analysis (TPA)

Table 5 shows the TPA results of the sausages. Textural properties of dry fermented sausages have significant influence on the consumer's perception of quality and consumers use the texture profile analysis parameters as an indicator to carry out personal quality control. Hardness, cohesiveness and springiness values are primary mechanical parameters to determine the textural properties of sausages. Hardness, springiness and chewiness values obtained in TPA analysis were highly correlated to sensory parameters, generally. In addition, the high values for these parameters in sausages have negative effects on the perception of sensorial properties by consumer (Chorbadzhiev et al. 2017). Furthermore, these parameters are also important in terms of giving an idea about the composition of the product such as protein, moisture and fat content. Texture is considered the most important characteristic of the sensory properties of sausages. Among all textural properties, hardness, which is the force required to achieve a certain deformation of sausage, is the most important parameter as it decides the commercial value of sausages. Springiness and cohesiveness reflect the visco-elastic properties of sausages. Adhesiveness is the work required to overcome the attractive forces between the surface of sausage and another contacted surface. Gumminess is the effort required to disintegrate sausage to the state ready to swallowing. Chewiness is the length of time required to masticate the sausage into a state ready for swallowing. Resilience is the parameter showing how well sausage regain its original height after deformation (Pandey et al. 2014). Results revealed that the use of β -glucan resulted in

Table 6 Microbiological properties of sausages at the end of the fermentation and storage periods

Groups	Sausage Dough	Sausage at the end of 7 days fermentation	End of 30 days Storage	Sausage Dough	Sausage at the end of 7 days fermentation	End of 30 days Storage
Coliform Count (log cfu/g)			Lactic acid Bacteria Count (log cfu/g)			
PC1	2.33 ± 0.27 ^{aA}	1.91 ± 0.27 ^{abB}	< 1.00	5.12 ± 0.05 ^{bC}	7.61 ± 0.05 ^{eB}	7.82 ± 0.05 ^{dA}
PC2	2.56 ± 0.44 ^{aA}	1.44 ± 0.44 ^{abcdB}	< 1.00	7.37 ± 0.41 ^{aC}	8.11 ± 0.08 ^{dB}	9.02 ± 0.33 ^{abcA}
NC1	2.49 ± 0.02 ^{aA}	1.37 ± 0.02 ^{abcdB}	< 1.00	5.19 ± 0.10 ^{bC}	7.68 ± 0.10 ^{eB}	7.89 ± 0.10 ^{dA}
NC2	2.78 ± 0.23 ^{aA}	1.66 ± 0.23 ^{abcdB}	< 1.00	6.94 ± 0.19 ^{aB}	8.43 ± 0.19 ^{bcA}	8.64 ± 0.19 ^{cA}
1	2.99 ± 0.26 ^{aA}	1.87 ± 0.26 ^{abcB}	< 1.00	6.95 ± 0.17 ^{aB}	9.24 ± 0.03 ^{aA}	9.35 ± 0.17 ^{abA}
2	1.69 ± 0.01 ^{aA}	0.93 ± 0.16 ^{cdB}	< 1.00	7.02 ± 0.08 ^{aB}	8.51 ± 0.09 ^{bcA}	8.72 ± 0.12 ^{bcA}
3	2.27 ± 0.18 ^{aA}	1.15 ± 0.18 ^{abcdB}	< 1.00	7.30 ± 0.42 ^{aB}	8.99 ± 0.14 ^{aA}	9.00 ± 0.42 ^{abcA}
4	2.44 ± 0.62 ^{aA}	1.32 ± 0.62 ^{abcdB}	< 1.00	7.15 ± 0.10 ^{aB}	8.64 ± 0.10 ^{ba}	8.85 ± 0.10 ^{abcA}
5	2.62 ± 0.67 ^{aA}	1.50 ± 0.67 ^{abcdB}	< 1.00	7.47 ± 0.55 ^{aB}	9.21 ± 0.20 ^{aA}	9.42 ± 0.20 ^{aA}
6	2.14 ± 1.47 ^{aA}	0.97 ± 0.69 ^{bcdB}	< 1.00	6.94 ± 0.19 ^{aB}	8.43 ± 0.19 ^{bcA}	8.64 ± 0.19 ^{cA}
7	1.96 ± 0.12 ^{aA}	0.84 ± 0.12 ^{dB}	< 1.00	7.41 ± 0.47 ^{aB}	9.15 ± 0.12 ^{aA}	9.26 ± 0.26 ^{abcA}
8	2.29 ± 0.83 ^{aA}	2.06 ± 0.14 ^{aB}	< 1.00	7.45 ± 0.53 ^{aC}	8.24 ± 0.10 ^{cdB}	9.15 ± 0.53 ^{abcA}
Total viable counts (log cfu/g)			Mould and yeast count (log cfu/g)			
PC1	6.58 ± 0.14 ^{abB}	8.53 ± 0.31 ^{bA}	8.94 ± 0.10 ^{aA}	4.41 ± 0.29 ^{aB}	5.61 ± 0.29 ^{aA}	5.87 ± 0.60 ^{aA}
PC2	7.91 ± 0.68 ^{aB}	9.54 ± 0.31 ^{aA}	9.40 ± 0.53 ^{aA}	4.48 ± 0.32 ^{aB}	5.68 ± 0.32 ^{aA}	5.94 ± 0.55 ^{aA}
NC1	6.35 ± 0.02 ^{bB}	8.46 ± 0.26 ^{bA}	8.97 ± 0.09 ^{aA}	4.63 ± 0.50 ^{aB}	5.83 ± 0.50 ^{aA}	5.78 ± 0.43 ^{aA}
NC2	7.81 ± 0.47 ^{aB}	9.36 ± 0.13 ^{aA}	9.30 ± 0.40 ^{aA}	4.62 ± 0.32 ^{aB}	5.79 ± 0.48 ^{aA}	5.98 ± 0.70 ^{aA}
1	7.98 ± 0.70 ^{aB}	9.53 ± 0.36 ^{aA}	9.38 ± 0.50 ^{aA}	4.62 ± 0.48 ^{aB}	5.82 ± 0.37 ^{aA}	5.92 ± 0.62 ^{aA}
2	7.92 ± 0.62 ^{aB}	9.47 ± 0.28 ^{aA}	9.08 ± 0.09 ^{aA}	4.65 ± 0.53 ^{aB}	5.85 ± 0.53 ^{aA}	5.86 ± 0.51 ^{aA}
3	7.84 ± 0.51 ^{aB}	9.39 ± 0.17 ^{aA}	9.40 ± 0.54 ^{aA}	4.22 ± 0.34 ^{aB}	5.42 ± 0.34 ^{aA}	5.75 ± 0.40 ^{aA}
4	7.54 ± 0.08 ^{abB}	9.23 ± 0.04 ^{aA}	9.18 ± 0.23 ^{aA}	4.68 ± 0.56 ^{aB}	5.88 ± 0.56 ^{aA}	5.93 ± 0.65 ^{aA}
5	7.97 ± 0.71 ^{aB}	9.52 ± 0.32 ^{aA}	9.52 ± 0.70 ^{aA}	4.60 ± 0.45 ^{aB}	5.80 ± 0.45 ^{aA}	5.60 ± 0.53 ^{aA}
6	7.95 ± 0.59 ^{aB}	9.54 ± 0.31 ^{aA}	9.19 ± 0.35 ^{aA}	4.47 ± 0.26 ^{aB}	5.67 ± 0.26 ^{aA}	5.74 ± 0.26 ^{aA}
7	7.96 ± 0.66 ^{aB}	9.50 ± 0.06 ^{aA}	9.29 ± 0.14 ^{aA}	4.73 ± 0.63 ^{aB}	5.93 ± 0.63 ^{aA}	5.95 ± 0.68 ^{aA}
8	7.93 ± 0.63 ^{aB}	9.53 ± 0.24 ^{aA}	9.37 ± 0.50 ^{aA}	4.51 ± 0.33 ^{aB}	5.71 ± 0.33 ^{aA}	5.52 ± 0.33 ^{aA}

All values are the mean ± standard error of three replicates

a–d (↓) Different letters within a column are significantly different ($P < 0.05$)

A–C (→) Different letters within a row are significantly different ($P < 0.05$)

an increase in hardness values of sausages compared to positive (PC1 and PC2) and negative controls (NC1 and NC2) ($P < 0.05$). Sausages with 2% β -glucan and beef fat (Groups 2, 4 and 6) had higher hardness values than the rest of the sausage groups produced with β -glucan ($P < 0.05$). Some previous studies about the utilization of β -glucan in frankfurters or low fat cooked sausages or meatballs have indicated that β -glucan is effective for improving textural properties and can be used as fat replacer in these products (Cofrades et al. 2000; Morin et al. 2002; Petersson et al. 2014). It is well established that animal fat plays important roles in textural characteristics of meat products (Fernandez-Gines et al. 2005; Hugo and Roodt 2007). Furthermore, there were no significant differences among all sausage treatment groups regarding adhesiveness, resilience, gumminess, chewiness, cohesiveness and springiness index. On the other hand, increasing the amount of

added β -glucan from 1 to 2% resulted in higher hardness values sausages ($P < 0.05$). Also, Alvarez and Barbut (2013) have indicated that there is a high correlation between textural properties and both fat and moisture contents of the meat products.

Sensory analysis

The results of the present study demonstrated that the addition of beta-glucan had no significant effect on the sensorial properties of sausages compared to control group (data is not presented). No significant differences were found between treatments for appearance attributes, juiciness, ease of fracture, firmness, greasiness, flavor, off-flavor, meat flavor intensity, off-odor and the overall acceptability. According to the texture profile analysis, the use of β -glucan resulted in an increase in hardness values

of sausages which was not confirmed by the results of sensory analysis. All treatment groups received high overall acceptability scores ranging 7–8 from panelists.

Microbiological analysis

The microbiological counts of sausage samples at the end of the fermentation ranged from 7.61 to 9.24 log cfu/g for lactic acid bacteria, from 8.46 to 9.54 log cfu/g for total viable bacteria, from 5.42 to 5.88 log cfu/g for mold and yeast, and from 0.84 to 2.06 log cfu/g for total coliform bacteria, respectively (Table 6).

Results indicated that PC1 and NC1 sausage groups had less lactic acid bacteria count compared to other groups manufactured using starter culture ($P < 0.05$). In addition, results of lactic acid bacteria count showed that the use of β -glucan significantly increased lactic acid bacteria count ($P < 0.05$). This may be associated with the prebiotic properties of β -glucan. Jaskari et al. (1998) described the prebiotic effect of β -glucan and reported that β -glucan is a potential prebiotic for some microorganisms such as *Lactobacilli* and *Bifidobacteria*. Similarly, Kilic and Akpinar (2013) reported that the addition of β -glucan into yogurt enhanced the growth of *L. Plantarum* strains. However, lactic acid bacteria count was reduced with increasing β -glucan addition from 1 to 2% ($P < 0.05$). Furthermore, β -glucan addition in the present study showed no significant effect on mold and yeast, total viable and coliform bacteria count of sausage groups.

Conclusion

The results indicated that the use of β -glucan in sausage formulation had no negative effects on the quality parameters of sausage such as fatty acid composition, color properties and physicochemical composition. In addition, regarding the results of TBARS, this study revealed that enhanced lipid oxidation inhibition in fermented sausages during fermentation and storage periods can be achieved by using β -glucan. It can be concluded that the utilization of β -glucan in meat product processing may provide a unique opportunity for the meat industry to meet consumer demands regarding a high quality meat products with improved nutritional value and shelf life.

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