Effects of autochthonous yeast cultures on some quality characteristics of traditional Turkish fermented sausage "Sucuk"

Ismet Ozturk[1*], Osman Sagdic[2], Hasan Yetim[3]

[1]Istanbul Arel University, Faculty of Fine Arts, Department of Gastronomy and Culinary Arts, Istanbul, Turkey
[2]Yildiz Technical University, Faculty of Chemical and Metallurgical Engineering, Department of Food Engineering, Istanbul-Turkey
[3] Istanbul Sabahattin Zaim University, Faculty of Engineering and Natural Sciences, Department of Food Engineering, Istanbul-Turkey

*:Corresponding author:
Istanbul Arel University,
Faculty of Fine Arts,
Department of Gastronomy and Culinary Arts,
34537, Istanbul, Turkey
Tel.: +90- 850 850 2735
Fax: +90- 212 860 04 81
E-mail address: iozturk34@gmail.com

Effects of autochthonous yeast cultures on some quality characteristics of traditional Turkish fermented sausage "Sucuk"

Abstract

The objective of this study was to determine the effects of yeast cultures (*Candida zeylanoides* and *Debaryomyces hansenii*) isolated from traditionally dry fermented Turkish sucuks, on some physicochemical and microbiological properties of the product. Eight different batches of the sucuks were produced by the inoculation of yeast and lactic acid bacteria (LAB) cultures (*Lactobacillus curvatus*, *L. plantarum* and *L. sakei*) in different combinations. The sucuks were ripened for 12 days and analyzed at 1^{st}, 6^{th} and 12^{th} days of ripening. Percent moisture content, pH, water activity (a_w) and residual nitrite values of the sucuk inoculated with the yeast cultures were higher at the end of the ripening. The use of yeast cultures decreased hardness, gumminess and chewiness values of the sucuk while increased adhesiveness values. Major volatile groups were aldehydes, terpenes and sulphur compounds in the sucuk samples. The most noticeable results were for sensory properties of the sucuk that were positively improved by the yeast cultures.

Keywords: Turkish fermented sucuk, indigenous yeast, texture, volatile

1. Introduction

Turkish sucuk is a traditionally fermented dry-cured sausage, which is commonly consumed in Turkey. Sucuk is produced using meat (beef, water buffalo), sheep tail fat or tallow, garlic salt, sugar, nitrite, nitrate, and some spices including red pepper, black pepper, cumin and pimento. In recent years, sucuk has been produced using either industrial method using heat treatment process by sucuk manufacturers. Ripening of sucuk takes a quite short time in the industrial method than that of the traditional process. Therefore, taste and aroma of sucuk are not well developed in case of industrial method (Kaban and Kaya, 2009; Gençcelep et al., 2007). Although industrial process is most widely used in sucuk production, some producers still use the traditional method. Fermented sucuk production can be performed including by spontaneous or commercial starter culture in the traditional process (Ozturk and Sagdic, 2014). In generally, commercial starter cultures are used to produce the standard-quality sucuk.

Lactic acid bacteria (*Lactobacillus sakei*, *Lb. plantarum*, *Lb. curvatus*, *Pediococcus acidilactici* and *P. pentosaceus*) and coagulase negative cocci (*Staphylococcus xylosus* and *S. carnosus* and *Kocuria varians*) are the most popular bacteria in commercial starter culture used in fermented sausage production (Toldra, 2001). Lactic acid bacteria (LAB) decrease the pH that is important in the formation of flavor and aroma and responsible for microbial safety of sucuk. Coagulase negative cocci (CNC) play an important role in the formation of desired biochemical reactions like proteolysis, lipolysis and color formation of the fermented sausage and sucuk (Toldra, 2001).

Yeasts and molds can also be effective in the fermentation of sucuk and sausage. Yeasts may have lipolytic and proteolytic activity, and it could contribute to aroma and flavor formation as well as color stability of the fermented sausages (Toldra, 2001; Durá et al., 2004; Flores et al., 2004). It has been known that *Debaryomyces hansenii* which is anamorph *Candida famata* is the most abundant species of yeast isolated from the fermented meat

products (Mendonça et al., 2013; Cocolin et al., 2006). *D. hansenii* is an osmophilic yeast species and can grow at low a_w and temperature levels. This species has poor ability to utilize lactose (Breuer and Harms, 2006), and *D. hansenii* can grow both in the interior part and on the surface of fermented meat products like sausage. Moreover, it is used as starter culture in the fermented sausages in some countries (Toldra, 2001). It has been speculated that *D. hansenii* can prevent formation of oxidation products of lipids in the fermented sausages and leads to formation of some aroma components (Flores et al., 2004). It can also play significant role in the degradation of organic acids like lactic and acetic acids and produce ammonia (Demeyer and Stahnke, 2002). Also, there is no evidence about the toxic effects and the pathogenicity for the both yeast species (Durá et al., 2004). Therefore, the aim of this study was to determine the effects of *D. hansenii* and *C. zeylanoides* strains isolated from traditional Turkish fermented sausage (Sucuk), on some physicochemical, textural properties and volatile components of the sucuk, a traditional Turkish dry-fermented sausage, produced with LAB starter cultures (*L. sakei, L. curvatus* and *L. plantarum*).

2. Materials and Methods

2.1. Materials

Fresh lean of beef from round region, tallow fat, spices (red pepper, black pepper, cumin, and pimento) and other ingredients (salt, fresh garlic, sugar and sodium nitrite) were supplied from local suppliers in Kayseri, Turkey.

2.2. Production of sucuk

In order to produce about 1 kg of sucuk, main ingredients [(ground lean beef (800 g), ground tallow fat (200 g)] and additives [salt (25 g), minced garlic (10 g), cumin (9 g), red pepper (7 g), black pepper (5 g), pimento (2.5 g), sugar (4 g) and sodium nitrite ($NaNO_2$ 150 mg)] were

prepared and incorporated together. First, all the ingredients were homogenized by kneading in a kitchen bowl approximately 10 min and the mass was divided into 8 batches as following: S1: Control (without starter culture), S2: LAB (*Lactobacillus curvatus*, *L. plantarum* and *L. sakei*), S3: LAB + *C. zeylanoides*, S4: LAB + *D. hansenii*, S5: LAB + *C. zeylanoides* + *D. hansenii*, S6: *C. zeylanoides*, S7: *D. hansenii* and S8: *C. zeylanoides* + *D. hansenii*. The LAB and yeast cultures were added at levels of approximately 10^8 and 10^6 cfu/g, respectively. The mixtures were filled into standard artificial collagen casings (diameter 30-32 mm) by using a filling machine (Tefal Le Hachoir 1500, France). Production of sucuk was carried out at room temperature (~22℃). The ripening of sucuks was carried out according to the following program: First 3 days at 24±1℃ and 90±2% relative humidity (RH), then following 4 days at 22±1℃ and 85±2% RH and finally for 5 days at 18±1℃ and 80±2% RH in fermentation cabinets (Nüve, TK 252, Ankara, Turkey). The sucuk samples were analyzed at 1st, 6th and 12th days of ripening. All the batches were produced as triplicate.

2.3. Microbiological analysis of sucuks

Twenty-five g of the sample was weighed into the sterile stomacher bag and homogenized with 225 mL of sterile Maximum Recovery Diluent solution (MRD, Merck, Germany) for 1.5 min using a homogenizer (Stomacher, IUL, Barcelona, Spain). Total mesophilic aerobic bacteria (TMAB) counts of the samples were determined after 48 h incubation at 30℃ on Plate Count Agar (PCA, Merck, Germany). LAB counts of the samples were determined in pour plates of De Man Rogosa and Sharpe Agar (MRS, Merck, Germany), after incubation for 48 h at 37℃ in anaerobic conditions. The number of Micrococcaceae on Mannitol Salt Phenol-Red agar (MSA, Merck, Germany) was determined after incubation for 48 h at 37℃. The Enterobacteriaceae counts were determined after incubation for 48h at 35℃, in anaerobic conditions on Violet Red Bile Glucose Agar (VRBG, Merck, Germany). Yeast and mold

124 counts were determined for 5 days at 25℃ on Dichloran Rose Bengal Chloramphenicol Agar
125 (DRBC, Merck, Germany). The microbiological analyses were carried out as triplicate.
126
127 **2.4. Physicochemical analyses of sucuks**
128 The moisture contents of the sucuk samples were determined by using oven air drying method
129 in a drying oven (Nüve FN 120, Ankara, Turkey) (AOAC, 2000). Water activities (a_w) of the
130 samples were determined using a_w meter (Aqua Lab 2.0, USA). To determine the pH values
131 of the sucuk samples, 10 g of the sucuk sample was homogenized with 100 ml of distilled
132 water using Ultraturrax (IKA T18 Basic, Germany) and the values were measured by using
133 pH meter (WTW, Inolab 720, Germany). Weight loss of the sucuk samples was determined
134 by recording the weights of the samples at the first day and 12th day of ripening. It was
135 calculated using the following equation:
136 $$Weight\ loss\ (\%) = \left(\frac{WB-WA}{WB}\right) \times 100$$
137 where WB and WA are the weights of a certain sample before and after ripening, respectively.
138 Residual nitrite level was determined based on the method described by Taucmann
139 (Taucmann, 1987). They were calculated the residual nitrite level using a calibration curve
140 and expressed as ppm of sodium nitrite ($NaNO_2$). The physicochemical analyses of the sucuk
141 samples were carried out as triplicate.
142
143 **2.5. Color properties**
144 Color properties of the sucuk samples were determined using an automatic colorimeter
145 (Konica Minolta, model CM-5, Mississauga, ON, Canada) at an observer angle of 10° with
146 the illuminant D_{65} and specular-component-excluded mode, according to The Commission
147 Internationale de l'Eclairage (CIE)-Lab color scales. Artificial collagen casing was removed

148 to measure color of the exterior part of the samples, and the cross-section of the sliced sucuk
149 samples was used to measure the internal color. The color results were expressed as L^*, a^*,
150 and b^*. L^* values measure the level of brightness (0–100), a^* redness (+ = red and − = green),
151 and b^* yellowness (+ = yellow and − = blue). Color parameter values of the sucuk samples
152 were measured in ten replicates.
153
154 **2.6. Volatile compounds**
155 Volatile compounds profile of the sucuk samples produced with different yeast and/or LAB
156 starter cultures was determined using a Gas Chromatographic-Mass Spectrometry (GC–MS)
157 (Agilent 7890A GC system, Agilent, Avondale, USA) equipped with a mass selective detector
158 (Agilent Technologies, Agilent, Avondale, USA) and HP5-MS capillary column (60
159 m × 0.250 mm i.d.; film thickness 0.25 μm) (Agilent, Palo Alto, CA, USA). Five g of the
160 sucuk sample was weighed into GC-MS vial (Agilent, Palo Alto, CA, USA). and the vial was
161 sealed with PTFE-faced silicone septum (Supelco, Bellefonte, PA, USA). Then vial was kept
162 in a termoblock (IKA, RCT basic, Germany) at 40℃ for 1 h. Then SPME fiber (75 μm, 23 ga,
163 carboxen/polydimethylsiloxane (CAR/PDMS)) (Supelco, Bellefonte, PA, USA) was subjected
164 to the headspace while maintaining the sample at 40℃ for 1 h. The volatile compounds
165 adsorbed by the fibers were desorbed from the injection port for 20 min at 50℃ and injected
166 to GC–MS in the splitless mode. The compounds were identified by comparison with spectra
167 from the libraries of Flavor 2, Nist05 and Wiley7n. GC–MS conditions were adjusted
168 according to Kaban and Kaya (2009). The volatile compound analyses were run as triplicate.
169
170 **2.7. Texture profile analysis (TPA)**
171 To determine textural properties of the sucuk samples, TPA test was conducted using a
172 texture analyzer (TA.XT Plus Texture Analyzer, Texture Technologies Corp. Scarsdale,

NY/Stable Micro System, UK). The sucuk samples ripened were cut into small pieces having a 20 mm diameter and 20±0.5 mm thickness. Firstly, the parameters of measurement were set to be following: pre test speed 2 mm/s, test speed 1 mm/s, post test speed 1 mm/s and compression (strain) level 25%. For the determination of TPA parameters, a spherical probe (SMS/1S) and 30 kg load cell were used. Hardness (g), adhesiveness (g s), springiness (mm), cohesiveness, gumminess (g), chewiness (g mm) and resilience values of the sucuk samples were measured by calculation using TPA curves (Bozkurt and Bayram 2006). Texture parameters of the sucuk samples were measured in ten replicates.

2.8. Statistical analysis

All the data were means of triplicate data with their standard deviations. Analysis of data was performed by using one-way ANOVA and/or two-way ANOVA. Duncan's Multiple Range Test was also applied to determine significant differences between means at the $p<0.05$ significance level using SAS 8.0 statistical software (SAS, 2000).

3. Results and Discussion

3.1. Physicochemical properties of sucuk samples

Some physicochemical properties of the sucuk samples prepared with *C. zeylanoides* (CZ), *D. hansenii* (DH) and LAB cultures are given in Table 1. Moisture contents of the sucuk samples varied from 54% to 57% in the first day of the ripening. Then, it decreased during ripening as expected depending on the dehydration of sucuks. Moisture contents of the sucuk samples (S2-S4) with LAB cultures were lower than that of the samples with CZ and DH at end of the ripening, and these results were also insignificant ($p>0.05$). Water activity (a_w) levels of the sucuk samples correlated with their moisture contents. Again, a_w values of the samples containing LAB were lower when compared to other samples at the 6^{th} and 12^{th} days. The pH

198 levels of the samples may be the reason for low moisture and a_w values of the samples
199 containing LAB. Low pH causes to decrease in water-holding capacity of the meat proteins.
200 This promotes the drying process of sucuk or fermented sausages (Ordóñez et al., 1999;
201 Toldra, 2001; Lücke, 1998). Additionally, higher pH value of meat is considered as a problem
202 in sucuk or fermented sausage production. When a meat having high pH is used in sucuk or
203 fermented sausage production, sufficient drying cannot be achieved due to high water
204 retention capacity (Toldra, 2007). Therefore, pH values of meats which will be used in sucuk
205 or fermented sausage should be in between 5.4 and 5.8 (Oztan, 2005). The pH values of the
206 sucuks were approximately 5.8 at the first day of the ripening, and the pH values of sucuks
207 produced with LAB cultures were lower than that of the control and samples inoculated yeast
208 culture at the end of the ripening. However, pH results were not ($P > 0.05$) different at first
209 and 12th days, but they were significantly different ($P < 0.05$) at 6th days of ripening. Andrade
210 et al., (2010) investigated effects of three *D. hansenii* strains on microbiological,
211 physiochemical properties and volatile compounds of salchichón, a dry fermented sausage.
212 They found a_w and pH values to be high in the samples with *D. hansenii* as compared to the
213 control sample at the end of ripening (54 days). In the same study, however, a_w and pH values
214 of fermented sausage changed depending on the *D. hansenii* strains. Kaban and Kaya (2009)
215 reported that pH and a_w values of sucuk samples produced with *L. plantarum* and
216 *Staphylococcus xylosus* were lower than that of the control sucuks. LAB are the bacteria
217 group that mainly responsible for pH decrease in fermented sausage and sucuks, and it affects
218 moisture and a_w values of fermented meat products during the ripening. In another study, dry
219 matter, a_w and pH values of dry fermented sausage produced with different yeast strains (*C.*
220 *famata*, *Yarrowia lipolytica*, *D. hansenii* and *Trichosporon mucoides*) were 66-68%, 0.81-
221 0.82% and 4.6-4.7%, respectively, after 21 days of ripening (Selgas et al., 2003). These results
222 are not in accordance with our findings probably due to fermentation time and conditions,

process applied and materials used such as starter culture, meat, spices and other additives. The Turkish Food Codex (2000) states that ripened sucuk which is high quality should have pH between 5.2 and 5.4. Again pH levels of the sucuk samples produced in the current study are not in line with Turkish Food Codex.

Weight loss values of the sucuk samples are seen in Figure 1. The highest weight loss values were determined in the sucuks produced with LAB cultures, and the differences were significant ($P < 0.05$) significant. However, use of the yeast cultures decreased weight loss of the sucuks. Weight loss is an important parameter for the economical reasons for the meat processors, it means saving money for the manufacturers.

Residual nitrite values of the sucuk samples are shown in Table 1. At the first day of ripening, nitrite values of the sucuks varied from 53.3 to 80.9 ppm, and it was the lowest in the sucuks produced with LAB cultures. The nitrite level significantly ($P < 0.05$) decreased with the ripening time. Again, the lowest residual nitrite values were in the sucuks produced with LAB culture and ranged between 8.1-9.8 ppm. Our residual nitrite results were in agreement with the results of Gençcelep et al., (2007) who reported that residual nitrite values of sucuks with starter culture were lower than those of the control group (without starter culture) sucuks. Nitrite is used to improve color and oxidative properties of the product, and it also inhibits *Clostridium botulinum* as well (Oh et al., 2004). However, it is at higher levels in foods a potential carcinogen and toxic agent for human (Cammack et al., 1999). According to the Turkish Food Codex (2000), residual nitrite levels of the fermented Turkish sucuks must be lower than 150 mg/kg. It has been reported that nitrite levels can be reduced by LAB having a nitrite reductase enzyme system (Fournaud and Mocquot, 1966). The nitrite values of the cured meat products decrease spontaneously during the storage period (Oh et al., 2004). Several studies have shown that certain LAB strains are able to degrade nitrite in the

247 fermented meat products (Oh et al., 2004; Yan et al., 2008; Dodds and Collins-Thompson,
248 1984).
249
250 **3.2. Microbiological properties**
251 Microbiological properties of the sucuk samples are given in Table 2. TMAB counts of the
252 samples were approximately 9.0 log cfu/g at the beginning of ripening. Then, it increased at
253 6^{th} days of the ripening and decreased at the end of ripening. TMAB and LAB counts of
254 samples were 9.85-10.21 log cfu/g and 9.89-10.17 log cfu/g, respectively and the differences
255 were not significant ($P > 0.05$) in the 12^{th} days of ripening. However, Micrococcaceae
256 population of the sucuk samples was different ($P < 0.05$) at the 6^{th} days and 12^{th} days of
257 ripening. Enterobacteriaceae numbers decreased during the ripening (Table 2). Yeast and
258 mold counts of the sucuk samples ranged from 4.12 to 6.10 log cfu/g at the beginning of the
259 ripening but they were closer to each other at the 6^{th} days of ripening. Additionally, use of CZ
260 and DH in the sucuk production affected ($P<0.05$) the yeast and mold counts as expected and
261 Micrococcaceae and Enterobacteriaceae counts as well, while the TMAB and LAB counts of
262 sucuk samples were not affected ($P>0.05$) from the presence of these yeasts at the end of
263 ripening. It was reported that LAB, Micrococcaceae and yeast counts of fermented sausage
264 produced with different *D. hansenii* strains were approximately 10^7, 10^3 and 10^4-10^5 cfu/g at
265 the end of ripening, respectively (Andrade et al., 2010). In another study, Bolumar et al.,
266 (2006) used *D. hansenii* and *L. sakei* to improve sensory properties of fermented dry sausage,
267 and yeast and LAB counts of ripened fermented sausage were determined as approximately
268 3.5 and 8.5 log cfu/g, respectively. At the same time, yeast count of fermented sausage
269 produced with only *D. hansenii* increased at the end of ripening while the number of LAB did
270 not change considerably during ripening. Durá et al., (2004) reported that yeast number
271 decreased during ripening of fermented sausage produced with two different *D. hansenii*

strains while the yeast count decreased in the control sample during ripening. Additionally, LAB counts of the samples were approximately 7 log cfu/g at the beginning of ripening and reached to approximately 9.5 log cfu/g within the ripening. These results were in accordance with our findings related to yeast and LAB counts (Table 2). Kaban and Kaya (2009) reported that Enterobacteriaceae was not detected in the control and the sucuk samples produced with starter culture (*L. plantarum* and *S. xylosus*) at the 7^{th} and 3^{rd} days of ripening, respectively. In this study, Enterobacteriaceae was present in the all sucuk samples after ripening, but their counts were low. It is known that Enterobacteriaceae is sensitive against low acidity and water activity (Kaban and Kaya, 2009). In this study, the pH and a_w values of the sucuks were higher than pH and a_w results of the sucuk samples produced by Kaban and Kaya (2009). Microbiological characteristics of fermented meat products are generally influenced from natural meat microbiota and starter cultures used.

3.3. Color

Color properties of the sucuk samples were determined in exterior and interior sections as shown in Table 3. The L* values of sucuks were found in the range 43.26-43.80 and 29.99-32.95 in the interior and exterior section, respectively. Use of LAB, CZ and DH starter cultures did not affect ($p>0.05$) the L* values of the sucuks in the neither interior nor exterior section. The a* values of sucuks were higher ($p>0.05$) in interior section. The highest a* value was in the S8 (CZ+DH), while the lowest value was determined in S2 sample (only LAB). However, the a* value of sucuks was lower ($p>0.05$) in the exterior part. Again, the highest and lowest a* values were in the S8 (CZ+DH) and S2 (only LAB) in the exterior part of sucuks, respectively (Table 3). The a* value is one of the most important color parameters for the quality of sucuk. The a* value is generally low at the beginning of ripening of dry-cured fermented meat products. However, it increases during the ripening due to the formation of

297 nitrosomyoglobin which is associated with the red color of fermented meat products and
298 moisture loss in the fermented meat products (Pérez-Alvarez et al., 1999). The reason of low
299 a* values may be acidity in the sucuks produced with LAB cultures. Because, lactic acid
300 produced by LAB might denature (partly or totally) the myoglobin during ripening (Pérez-
301 Alvarez et al., 1999). The b* values of sucuk samples were variable ($P<0.05$) in both interior
302 and exterior section. As L* and a* values of sucuks, the b* values were high in the interior
303 section of sucuk samples.
304
305 **3.4. Texture profile**
306 Textural properties including hardness, adhesiveness, springiness, cohesiveness, gumminess,
307 chewiness and resilience parameters were determined in the ripened sucuk samples (at the 12^{th}
308 days of ripening), and these results are shown in Figure 2. Hardness values of the sucuks with
309 LAB cultures were higher than those of the sucuks without LAB cultures and control group.
310 In general, use of LAB and yeast cultures affected ($P<0.05$) the hardness of the sucuk samples.
311 The highest hardness value was found in the sucuk sample produced by only LAB cultures
312 (S2) while the lowest hardness was determined for the sucuk with DH culture. Again, in
313 general, the presence of CZ and DH cultures decreased hardness values of sucuk samples.
314 This result might be due to low pH value and higher moisture loss of the sucuk samples.
315 Adhesiveness values of sucuk were different ($P<0.05$) from each other, and it was higher in
316 sucuk samples with yeast cultures compared to the sample produced with only LAB culture
317 (S2). Adhesiveness values were -27.46 (g.sn) and -20.42 (g.sn) for S2 and S3 sucuks,
318 respectively, and it was -9.99 (g.sn) in control sample (S1). However, it ranged from -4.60 to -
319 13.58 (g.sn) and was higher for the sucuk sample produced without LAB culture. Springiness
320 and cohesiveness values of the sucuk produced using yeast culture were lower than those of
321 the sample with LAB culture. Use of only yeast culture on sucuk significantly ($P<0.05$)

decreased both springiness and cohesiveness values (Figure 2). Especially, it was lower in sucuks only with DH (S7) or CZ+DH (S8) samples, and it was 0.57 and 0.59 for in S7, respectively. However, springiness and cohesiveness values were higher in S4 and S5 samples (yeast + LAB cultures) than that of the S7 and S8 sucuks (yeast cultures). Although use of LAB cultures increased gumminess values of sucuk, use of only yeast cultures in formulation decreased that parameter. Gumminess values of the samples ranged from 316.7 to 701.7. The lowest gumminess values were determined as 316.7 and 360.4 in S7 and S8 samples, respectively. Chewiness values were similar to gumminess and ranged between 181.6 and 469.5 (Figure 2). Again, both parameters were lower in sucuk samples (S5-S8) produced with only used yeast cultures. Both gumminess and chewiness values of the sucuk samples were significantly ($P<0.05$) different. Resilience values of the sucuk samples varied from 0.18 to 0.20, and it was lower in the samples with CZ and DH.

Limited numbers of studies are available related to effects of yeast starter cultures (*D. hansenii*) on textural properties of fermented sausages, and there is no report for the sucuk in the literature. In a study performed on Portuguese traditional sausage, use of *Lactobacillus* spp., Micrococcaceae and yeasts in production of fermented sausage slightly improved the cohesiveness properties of sausage, and other textural properties including hardness, adhesiveness, springiness, gumminess, chewiness and resilience were not significantly affected (Elias et al., 2014). In another study, *D. hansenii* affected the hardness and chewiness values, while no effect was observed on springiness and cohesiveness properties of sausage (Corral et al., 2014). In the current study, use of yeast culture significantly ($P<0.05$) affected the textural properties of sucuk (Figure 2).

In general, microbial growth decreases pH level of sausages during the ripening. It leads to drying of sausage, and the denaturation and gelation properties of meat proteins. This affects hardness values of sausage (Bozkurt and Bayram 2006; Wu et al., 2010). Lower

moisture levels in sausage also decrease the adhesiveness values, improving cutting ability of the product (Bozkurt and Bayram, 2006).

3.5. Volatile profile

Volatile composition of the sucuk samples is given in Table 4. In this study, total 85 volatile compounds were identified in the sucuk samples, and volatile compounds were in the following groups: 5 aldehydes, 2 alkanes, 2 alkines, 7 acids, 8 alcohols, 5 esters, 19 sulphur compounds, 31 terpenes, 3 aromatic hydrocarbons and 3 other components. Cuminaldehyde, di-2-propenyl disulfide and p-cymene were the major volatile aldehydes, sulphur compounds and terpenes, respectively. Again, eugenol, carvacrol and naphthalene were the aromatic hydrocarbons observed in the sucuk samples.

Cuminaldehyde level in the volatile compounds decreased gradually during the ripening, and it was lower in the sucuk samples produced with LAB cultures at the end of ripening. However, the *p*-cymene, γ-terpinene, β-caryophyllene and limonene levels were higher in the samples produced with LAB cultures at the end of the ripening. Safranal was one of the major terpenes and was higher level in the control group and the sample produced with only yeast cultures. Propionic (propanoic) acid was detected in the sucuk samples produced only with yeast cultures at the end of ripening, and its level was 0.31 % and 0.32 % in S6 and S8, respectively. These samples were prepared with CZ yeast culture. Butyric acid was not detected at 6^{th} and 12^{th} days of ripening while it was observed at the beginning of the ripening. However, stearic acid, palmitic acid and 9-octadecenoic acid (oleic) which are fatty acids were determined in sucuk samples produced only with yeast cultures at the end of ripening. It was speculated that the degradation of free fatty acids to volatile compounds may have caused to these results (Flores and Olivares, 2015). Also the yeast species having lipolytic activity are

371 able to hydrolyze fatty acids during the ripening, because CZ and DH cultures used in this
372 study have lipolytic activity too (Ozturk and Sagdic, 2014).

373 The flavor properties of fermented sausages are associated with breakdown of
374 carbohydrates, lipids and proteins by enzymes which are microbial origin and/or endogenous
375 meat enzymes (Kaban and Kaya 2009; Flores and Olivares, 2015; Ansorena et al., 2001).
376 Volatile compounds of fermented sausages can be also affected from meat origin, type of
377 starter culture, process conditions and the spices used in production (Toldra, 2001, Kaban and
378 Kaya 2009; Leroy et al., 2006). Terpenes and sulphur compounds are important volatile
379 compound groups in ripened meat products. Terpenes generally originate from spices used in
380 production of fermented sausages as well as arise from the meat which based on animal
381 nutrition with some terpenes (Ansorena et al., 2001). Again, cuminaldehyde, limonene,
382 carvacrol and safranal can be resulted from cumin used in production of sucuk (Ağaoğlu 2007,
383 Li and Jiang 2004). While benzaldehyde, benzeneacetaldehyde and phenethyl alcohol
384 compounds determined in the samples are the yields of degradation of amino acids (bacterial
385 metabolism), 1-hexanol, propanoic acid and hexanoic acid comprise by lipid autooxidation in
386 fermented sausages (Olivares et al., 2011; Corral et al., 2013). Kaban and Kaya (2009) found
387 that major volatile compounds were 2-methyl-3-phenyl propanal, o-cymene, γ -terpinene and
388 di-2-propenyl disulfide in sucuks produced with *L. plantarum* and *S. xylosus.* In another study,
389 major volatile compounds of traditional sucuk samples were terpenes (o-cymene, γ -terpinene),
390 acids (acetic acid), aldehydes (propanal,2-methyl-3-phenyl) and sulphur compounds (1-
391 Propene,3,3'-thiobis) (Kaban, 2010). Küçüktaş (2012) isolated 38 volatile compounds from
392 sucuk samples produced with yeast cultures (*Y. lipolytica* and *D. hansenii*) during ripening
393 and major volatile compounds of sucuk were terpenes and sulphur compounds at the 9th day of
394 ripening. However, some volatile compounds such as acetic acid, 2-methylpentanoic acid, 2-
395 hydroxypropanoic acid, hexanoic acid ethanol, 1-pentanol, 1-hexanol and benzyl alcohol were

reported as yields of lipid autooxidation, carbohydrate fermentation and amino acid degradation in that study. When considering this volatile composition of fermented sausages, some differences are available between the findings of the current study and literature. Analysis of volatile compounds of fermented sausage and other similar fermented meat products could be affected from several other factors such as solid phase microextraction (SPME), column and method conditions as well as meat origin, type of starter culture, process conditions and the spices used.

Conclusion

In this research, the effects of yeast cultures (*Candida zeylanoides* and *Debaryomyces hansenii*) isolated from traditionally dry fermented Turkish sucuks, on some properties of the sucuk samples were determined. In the results, use of the yeast cultures (*C. zeylanoides* and *D. hansenii*) in the sucuk affected a_w and residual nitrite levels, moisture content and pH values as well. Again, it was noted that weight loss of the sucuks were decreased by use of the yeast cultures. Propionic (propanoic) acid, stearic acid, palmitic acid and 9-octadecenoic acid compounds were found only in the sucuk samples produced with the yeast cultures. Textural properties of the sucuks were also affected by the use of yeast cultures. It might be concluded that further studies are necessary to improve technological, sensory, textural and aromatic properties of the sucuk, dry fermented sausage by using different strains of *D. hansenii* and *C. zeylanoides* or other beneficial yeast species originate from the fermented sausages. Again, more research is needed on how yeasts prevent weight loss in fermented sausages that noted in this study.

Conflict of Interest

All authors declare that there is no conflict of interest.

Acknowledgements

This study was supported by Erciyes University, Scientific Research Projects Coordination Unit (FBA-10-3330 and FBD-10-3347).

Author Contributions

Conceptualization: Ozturk I, Sagdic O., Data curation: Ozturk I., Formal analysis: Ozturk I., Methodology: Ozturk I., Validation: Ozturk I., Investigation: Ozturk I, Sagdic O., Writing - original draft: Ozturk I, Sagdic O, Yetim H., Writing - review & editing: Ozturk I, Sagdic O, Yetim H.

Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

References

Ağaoğlu S, Dostbil, N., Alemdar, S. 2007. Antimicrobial Activity of Some Spices Used in The Meat Industry. Bull Vet Inst Pulawy 51:53-7.

Andrade MJ, Córdoba JJ, Casado EM, Córdoba MG, Rodríguez M. 2010. Effect of selected strains of Debaryomyces hansenii on the volatile compound production of dry fermented sausage "salchichón". Meat Sci 85(2):256-64.

Ansorena D, Gimeno O, Astiasarán I, Bello J. 2001. Analysis of volatile compounds by GC-MS of a dry fermented sausage: Chorizo de Pamplona. Food Res Int 34(1):67-75.

AOAC, (2000).Official methods of analysis (15th ed.), Method 950.46, Washington DC: Association of Official Analytical Chemists.

Bolumar T, Sanz Y, Flores M, Aristoy MC, Toldrá F, Flores J. 2006. Sensory improvement of dry-fermented sausages by the addition of cell-free extracts from *Debaryomyces hansenii* and *Lactobacillus sakei*. Meat Sci 72(3):457-66.

449 Bozkurt H, Bayram M. 2006. Colour and textural attributes of sucuk during ripening. Meat
450 Sci 73(2):344-50.

451 Breuer U, Harms H. 2006. *Debaryomyces hansenii* - An extremophilic yeast with
452 biotechnological potential. Yeast 23(6):415-37.

453 Cammack R, Joannou CL, Cui X-Y, Torres Martinez C, Maraj SR, Hughes MN. 1999. Nitrite
454 and nitrosyl compounds in food preservation. Biochim Biophys Acta Biomembr
455 1411(2–3):475-88.

456 Cano-García L, Belloch C, Flores M. 2014. Impact of Debaryomyces hansenii strains
457 inoculation on the quality of slow dry-cured fermented sausages. Meat Sci 96(4):1469-
458 77.

459 Cocolin L, Urso R, Rantsiou K, Cantoni C, Comi G. 2006. Dynamics and characterization of
460 yeasts during natural fermentation of Italian sausages. FEMS Yeast Res 6:692-701.

461 Corral S, Salvador A, Belloch C, Flores M. 2014. Effect of fat and salt reduction on the
462 sensory quality of slow fermented sausages inoculated with *Debaryomyces hansenii*
463 yeast. Food Control 45:1-7.

464 Corral S, Salvador A, Flores M. 2013. Salt reduction in slow fermented sausages affects the
465 generation of aroma active compounds. Meat Sci 93(3):776-85.

466 Demeyer D, Stahnke L. 2002. Quality control of fermented meat products. In: Kerry J K, J
467 LD, editors. Meat processing improving quality. Boca Raton, Fla.: CRC Press. . p.
468 359-82.

469 Dodds KL, Collins-Thompson DL. 1984. Nitrite tolerance and nitrite reduction in lactic acid
470 bacteria associated with cured meat products. Int J Food Microbiol 1(3):163-70.

471 Durá MA, Flores M, Toldrá F. 2004. Effect of *Debaryomyces* spp. on the proteolysis of dry-
472 fermented sausages. Meat Sci 68(2):319-28.

473 Elias M, Potes ME, Roseiro LC, Santos C, Gomes A, Agulheiro-Santos AC. 2014. The Effect
474 of Starter Cultures onthe Portuguese Traditional Sausage "Paio do Alentejo" in Terms
475 of Its Sensory and Textural Characteristics and Polycyclic Aromatic Hydrocarbons
476 Profile. J Food Res 3:45-56.

477 Flores M, Durá MA, Marco A, Toldrá F. 2004. Effect of Debaryomyces spp. on aroma
478 formation and sensory quality of dry-fermented sausages. Meat Sci 68(3):439-46.

479 Flores M, Olivares A. 2015. Flavor (chap. 25). In: Toldrá F, editor. Handbook of Fermented
480 Meat and Poultry, 2nd John Wiley and Sons, Ltd. p. 217-25.

481 Fournaud J, Mocquot G. 1966. Study of the reduction of the nitrite ion by certain lactobacilli.
482 C R Acad Hebd Seances Acad Sci D 262(1):230-2.

483 Gençcelep H, Kaban G, Kaya M. 2007. Effects of starter cultures and nitrite levels on
484 formation of biogenic amines in sucuk. Meat Sci 77(3):424-30.

485 Iucci L, Patrignani F, Belletti N, Ndagijimana M, Elisabetta Guerzoni M, Gardini F, Lanciotti
486 R. 2007. Role of surface-inoculated *Debaryomyces hansenii* and *Yarrowia lipolytica*
487 strains in dried fermented sausage manufacture. Part 2: Evaluation of their effects on
488 sensory quality and biogenic amine content. Meat Sci 75(4):669-75.

489 Kaban G. 2010. Volatile Compounds of Traditional Turkish Dry Fermented Sausage (Sucuk).
490 Int J Food Prop 13(3):525-34.

491 Kaban G, Kaya M. 2009. Effects of *Lactobacillus plantarum* and *Staphylococcus xylosus* on
492 the quality characteristics of dry fermented sausage "sucuk". J Food Sci 74(1):S58-S63.

493 Küçüktaş D. 2012. Effects of Yeast Species on Quality Characteristics of Fermented Turkish
494 Sausages. [PhD Thesis]. Izmir: Izmir Institute of Technology, Graduate School of
495 Engineering and Sciences.

496 Leroy F, Verluyten J, De Vuyst L. 2006. Functional meat starter cultures for improved
497 sausage fermentation. Int J Food Microbiol 106(3):270-85.

498 Li R, Jiang Z-T. 2004. Chemical composition of the essential oil of *Cuminum cyminum* L.
499 from China. Flavour Frag J 19(4):311-3.

500 Lücke FK. 1998. Fermented sausages. In: BJB W, editor. Microbiology of fermented foods.
501 London, U.K.: Blackie Academic & Professional. p. 441–83.

502 Mendonça RCS, Gouvêa DM, Hungaro HM, Sodré ADF, Querol-Simon A. 2013. Dynamics
503 of the yeast flora in artisanal country style and industrial dry cured sausage (yeast in
504 fermented sausage). Food Control 29(1):143-8.

505 Oh CK, Oh MC, Kim SH. 2004. The Depletion of Sodium Nitrite by Lactic Acid Bacteria
506 Isolated from Kimchi. J Medic Food 7(1):38-44.

507 Olesen PT, Stahnke LH. 2000. The influence of Debaryomyces hansenii and Candida utilis on
508 the aroma formation in garlic spiced fermented sausages and model minces. Meat Sci
509 56(4):357-68.

510 Olivares A, Navarro JL, Flores M. 2011. Effect of fat content on aroma generation during
511 processing of dry fermented sausages. Meat Sci 87(3):264-73.

512 Ordóñez JA, Hierro EM, Bruna JM, De La Hoz L. 1999. Changes in the components of dry-
513 fermented sausages during ripening. Crit Rev Food Sci Nutr 39(4):329-67.

514 Oztan A. 2005. Et Bilimi ve Teknolojisi, 4th ed., p:347. Ankara: Union of Chambers of
515 Turkish Engineers and Architects, Chamber of Food Engineers Publishing (in Turkish).

516 Ozturk I, Sagdic O. 2014. Biodiversity of yeast mycobiota in "sucuk," a traditional turkish
517 fermented dry sausage: Phenotypic and genotypic identification, functional and
518 technological properties. J Food Sci 79(11):M2315-M22.

519 Pérez-Alvarez JA, Sayas-Barberá MaE, Fernández-López J, Aranda-Catalá V. 1999.
520 Physicochemical characteristics of Spanish-type dry-cured sausage. Food Res Int
521 32(9):599-607.

522 SAS. 2000 SAS/STAT User's Guide (version 8.2). Cary, NC: SAS Institute Inc.

523 Selgas MD, Ros J, García ML. 2003. Effect of selected yeast strains on the sensory properties
524 of dry fermented sausages. Eur Food Res Technol 217(6):475-80.

525 Taucmann F. 1987. Methoden der chemischen analytik von fleisch und fleischwaren
526 bundensanstalt fur fleischgforschung. 80s, Klumbach.

527 Toldra F. 2007. Biochemistry of Meat and Fat. In: Toldra F, editor. Handbook of Fermented
528 Meat and Poultry. Iowa, USA: Blackwell Publishing Professional. p. 51-8.

529 Toldra F, Sanz, Y. Lores, M. 2001. Meat Fermentation Technology. In: Hui YH, editor. Meat
530 Science Applications. New York: Marcel Dekker Incorporated.

531 Wu Y, Zhao M, Yang BAO, Sun W, Cui C, Mu L. 2010. Microbial Analysis and Textural
532 Properties of Cantonese Sausage. J Food Proc Eng 33(1):2-14.

533 Yan P-M, Xue W-T, Tan S-S, Zhang H, Chang X-H. 2008. Effect of inoculating lactic acid
534 bacteria starter cultures on the nitrite concentration of fermenting Chinese paocai.
535 Food Control 19(1):50-5.

536

537

538 **Table 1.** Physicochemical properties of the sucuk samples during ripening period

Batches	Ripening period (day)		
	1st	6th	12th
	Moisture (%)		
S1	$55.63^{Abc}\pm1.42$	$45.18^{Ba}\pm3.23$	$36.74^{Ca}\pm1.70$
S2	$57.13^{Aab}\pm0.54$	$46.56^{Ba}\pm0.99$	$35.40^{Ca}\pm2.67$
S3	$57.77^{Aa}\pm1.88$	$45.54^{Ba}\pm2.66$	$35.46^{Ca}\pm1.46$
S4	$57.41^{Aab}\pm0.77$	$46.40^{Ba}\pm1.81$	$35.82^{Ca}\pm0.66$
S5	$57.76^{Aa}\pm0.70$	$46.74^{Ba}\pm4.03$	$37.73^{Ca}\pm2.45$
S6	$56.97^{Aabc}\pm1.35$	$46.56^{Ba}\pm1.69$	$37.48^{Ca}\pm0.70$
S7	$54.99^{Ac}\pm0.75$	$46.84^{Ba}\pm1.49$	$38.45^{Ca}\pm0.12$
S8	$56.76^{Aabc}\pm0.44$	$47.18^{Ba}\pm1.45$	$37.44^{Ca}\pm1.76$
	pH		
S1	$5.84^{Aa}\pm0.05$	$5.01^{Ba}\pm0.16$	$5.08^{Ba}\pm0.10$
S2	$5.86^{Aa}\pm0.03$	$4.74^{Bb}\pm0.02$	$4.90^{Ba}\pm0.17$
S3	$5.86^{Aa}\pm0.02$	$4.75^{Bb}\pm0.05$	$4.90^{Ba}\pm0.17$
S4	$5.85^{Aa}\pm0.03$	$4.76^{Cb}\pm0.04$	$4.92^{Ba}\pm0.07$
S5	$5.84^{Aa}\pm0.04$	$4.80^{Bb}\pm0.01$	$4.98^{Ba}\pm0.13$
S6	$5.87^{Aa}\pm0.01$	$4.98^{Ba}\pm0.02$	$5.13^{Ba}\pm0.17$
S7	$5.88^{Aa}\pm0.01$	$5.01^{Ba}\pm0.04$	$5.06^{Ba}\pm0.11$
S8	$5.88^{Aa}\pm0.01$	$4.99^{Ba}\pm0.05$	$5.08^{Ba}\pm0.16$
	a_w		
S1	$0.962^{Aa}\pm0.003$	$0.937^{Bab}\pm0.003$	$0.891^{Cb}\pm0.015$
S2	$0.961^{Aa}\pm0.003$	$0.920^{Bc}\pm0.005$	$0.876^{Cc}\pm0.010$
S3	$0.964^{Aa}\pm0.001$	$0.932^{Bb}\pm0.003$	$0.891^{Cb}\pm0.004$
S4	$0.964^{Aa}\pm0.001$	$0.938^{Bab}\pm0.002$	$0.895^{Cab}\pm0.003$
S5	$0.963^{Aa}\pm0.002$	$0.938^{Bab}\pm0.006$	$0.900^{Cab}\pm0.006$
S6	$0.965^{Aa}\pm0.003$	$0.943^{Ba}\pm0.004$	$0.904^{Cab}\pm0.007$
S7	$0.961^{Aa}\pm0.002$	$0.942^{Ba}\pm0.004$	$0.903^{Cab}\pm0.005$
S8	$0.963^{Aa}\pm0.002$	$0.943^{Ba}\pm0.005$	$0.907^{Ca}\pm0.003$
	Residual nitrite (ppm)		
S1	$80.6^{Aa}\pm3.8$	$15.6^{Ba}\pm1.7$	$14.6^{Bab}\pm0.5$
S2	$54.7^{Ac}\pm5.0$	$9.4^{Bb}\pm2.2$	$8.1^{Bc}\pm0.8$
S3	$53.3^{Ac}\pm5.5$	$9.1^{Bb}\pm2.2$	$8.8^{Bc}\pm1.1$
S4	$71.0^{Ab}\pm3.1$	$9.0^{Bb}\pm1.6$	$9.8^{Bc}\pm0.2$
S5	$68.6^{Ab}\pm3.2$	$10.1^{Bb}\pm1.9$	$8.2^{Bc}\pm1.1$
S6	$78.2^{Aa}\pm2.3$	$14.9^{Ba}\pm2.2$	$14.9^{Bab}\pm3.4$
S7	$79.4^{Aa}\pm1.6$	$16.1^{Ba}\pm0.2$	$15.5^{Ba}\pm0.4$
S8	$80.9^{Aa}\pm4.6$	$14.5^{Ba}\pm1.4$	$13.5^{Bb}\pm1.1$

539 **S1**: Control, **S2**: LAB, **S3**: LAB+*C. zeylanoides*, **S4**: LAB+*D. hansenii*, **S5**:LAB+*C. zeylanoides*+*D. hansenii*,
540 **S6**: *C. zeylanoides*, **S7**: *D. hansenii*, **S8**:*C. zeylanoides*+*D. hansenii*, $^{A-C}$: The uppercase within the same line
541 show that the results are not significantly different (p> 0.05), $^{a-c}$: The lowercase within the same column show
542 that the results are not significantly different (p> 0.05) for physicochemical properties of sucuk samples
543

Table 2. Microbiological results of the sucuk samples during ripening period (log cfu/g)

Batches	Ripening period (day)		
	1st	6th	12th
		TMAB	
S1	$9.13^{Babc}\pm0.68$	$10.17^{Aa}\pm0.26$	$9.92^{ABa}\pm0.19$
S2	$9.60^{Bab}\pm0.38$	$10.60^{Aa}\pm0.31$	$9.85^{ABa}\pm0.44$
S3	$9.62^{Bab}\pm0.13$	$10.53^{Aa}\pm0.43$	$10.01^{ABa}\pm0.21$
S4	$9.71^{Bab}\pm0.26$	$10.47^{Aa}\pm0.14$	$10.15^{ABa}\pm0.28$
S5	$9.83^{Ba}\pm0.21$	$10.33^{Aa}\pm0.16$	$10.18^{ABa}\pm0.20$
S6	$9.03^{Bbc}\pm0.30$	$10.32^{Aa}\pm0.25$	$10.21^{Aa}\pm0.26$
S7	$8.95^{Bbc}\pm0.49$	$10.29^{Aa}\pm0.06$	$9.96^{Aa}\pm0.50$
S8	$8.66^{Bc}\pm0.52$	$10.26^{Aa}\pm0.14$	$10.11^{Aa}\pm0.18$
		LAB	
S1	$8.81^{Bb}\pm0.51$	$10.07^{Aa}\pm0.15$	$9.94^{Aa}\pm0.10$
S2	$9.61^{Ba}\pm0.34$	$10.64^{Aa}\pm0.28$	$9.89^{Ba}\pm0.30$
S3	$9.59^{Ba}\pm0.16$	$10.34^{Aa}\pm0.50$	$9.97^{ABa}\pm0.24$
S4	$9.20^{Bab}\pm0.24$	$10.67^{Aa}\pm0.56$	$10.14^{Aa}\pm0.28$
S5	$9.70^{Ba}\pm0.27$	$10.51^{Aa}\pm0.36$	$10.17^{ABa}\pm0.14$
S6	$8.74^{Bb}\pm0.51$	$9.91^{Aa}\pm0.09$	$10.17^{Aa}\pm0.29$
S7	$8.64^{Bb}\pm0.44$	$10.62^{Aa}\pm0.68$	$9.92^{Aa}\pm0.45$
S8	$8.83^{Bb}\pm0.61$	$10.19^{Aa}\pm0.18$	$10.08^{Aa}\pm0.34$
		Micrococcaceae	
S1	$6.33^{Aa}\pm0.55$	$7.01^{Aa}\pm0.14$	$7.08^{Aa}\pm0.45$
S2	$5.61^{Aa}\pm1.20$	$5.95^{Acd}\pm0.31$	$5.99^{Abc}\pm0.42$
S3	$5.61^{Aa}\pm1.14$	$5.79^{Ad}\pm0.72$	$5.70^{Ac}\pm0.67$
S4	$5.72^{Aa}\pm1.07$	$5.99^{Abcd}\pm0.39$	$5.72^{Ac}\pm0.46$
S5	$5.63^{Aa}\pm1.29$	$5.92^{Acd}\pm0.78$	$6.55^{Aabc}\pm0.86$
S6	$6.49^{Aa}\pm0.32$	$6.84^{Aa}\pm0.18$	$7.22^{Aa}\pm0.65$
S7	$6.27^{Ba}\pm0.40$	$6.77^{ABab}\pm0.30$	$6.97^{Aab}\pm0.13$
S8	$6.33^{Aa}\pm0.38$	$6.73^{Aabc}\pm0.10$	$7.22^{Aa}\pm0.66$
		Enterobacteriaceae	
S1	$5.36^{Aa}\pm0.35$	$3.79^{Ba}\pm0.98$	$2.32^{Cab}\pm0.15$
S2	$4.03^{Ab}\pm0.71$	$2.90^{Bb}\pm0.53$	$2.13^{Bb}\pm0.12$
S3	$4.65^{Aab}\pm0.36$	$2.74^{Bb}\pm0.18$	$2.15^{Cab}\pm0.15$
S4	$4.48^{Aab}\pm0.68$	$2.64^{Bb}\pm0.29$	$2.10^{Bb}\pm0.09$
S5	$3.81^{Ab}\pm0.94$	$2.82^{ABb}\pm0.43$	$2.12^{Bb}\pm0.20$
S6	$5.35^{Aa}\pm0.17$	$3.17^{Bab}\pm0.39$	$2.31^{Cab}\pm0.28$
S7	$5.48^{Aa}\pm0.44$	$2.83^{Bb}\pm0.39$	$2.52^{Ba}\pm0.26$
S8	$5.24^{Aa}\pm0.75$	$2.87^{Bb}\pm0.22$	$2.21^{Bab}\pm0.24$
		Yeast and Mold	
S1	$4.59^{Abc}\pm0.31$	$5.02^{Ab}\pm0.55$	$4.78^{Ab}\pm0.42$
S2	$4.12^{Bc}\pm0.85$	$5.61^{Aab}\pm0.07$	$5.37^{Ab}\pm0.58$
S3	$5.56^{Aab}\pm0.47$	$5.76^{Aab}\pm0.46$	$5.60^{Ab}\pm1.07$
S4	$5.13^{Aabc}\pm0.65$	$5.51^{Aab}\pm0.31$	$5.24^{Ab}\pm0.82$
S5	$5.35^{Bab}\pm1.07$	$5.50^{Bab}\pm0.60$	$7.01^{Aa}\pm0.24$
S6	$6.10^{Aa}\pm0.20$	$5.91^{Aa}\pm0.42$	$5.91^{Ab}\pm0.55$
S7	$5.81^{Aa}\pm0.20$	$5.39^{Aab}\pm0.16$	$5.04^{Ab}\pm0.23$
S8	$6.05^{Aa}\pm0.13$	$5.39^{Aab}\pm0.09$	$5.46^{Ab}\pm0.61$

S1: Control, **S2**: LAB, **S3**: LAB+*C. zeylanoides*, **S4**: LAB+*D. hansenii*, **S5**: LAB+*C. zeylanoides*+*D. hansenii*, **S6**: *C. zeylanoides*, **S7**: *D. hansenii*, **S8**:*C. zeylanoides*+*D. hansenii***, TMAB**: Total mesophilic aerobic bacteria, **LAB**: Lactic acid bacteria, **$^{A-C}$:** The uppercase within the same line show that the results are not significantly different (p> 0.05),**$^{a-d}$**: The lowercase within the same column show that the results are not significantly different (p> 0.05) for microbiological properties of sucuk samples

552 **Table 3.** Color parameters of the ripened sucuk samples

Batches	*L**	*a**	*b**
	Internal section		
S1	$42.26^{A}\pm1.12$	$17.18^{A}\pm1.26$	$5.13^{BC}\pm0.99$
S2	$42.57^{A}\pm1.48$	$16.77^{A}\pm1.34$	$4.45^{C}\pm0.36$
S3	$43.80^{A}\pm1.38$	$17.05^{A}\pm1.35$	$5.87^{ABC}\pm0.95$
S4	$42.74^{A}\pm1.85$	$17.70^{A}\pm2.07$	$6.01^{ABC}\pm1.40$
S5	$42.71^{A}\pm1.55$	$17.69^{A}\pm1.96$	$5.49^{ABC}\pm0.97$
S6	$42.92^{A}\pm1.65$	$17.96^{A}\pm1.40$	$7.11^{A}\pm0.84$
S7	$42.66^{A}\pm1.50$	$17.70^{A}\pm0.43$	$6.83^{AB}\pm0.93$
S8	$42.66^{A}\pm1.14$	$18.39^{A}\pm0.96$	$7.05^{A}\pm0.76$
	Exterior part		
S1	$32.63^{A}\pm3.48$	$14.24^{A}\pm2.05$	$1.75^{C}\pm0.25$
S2	$29.99^{A}\pm2.84$	$12.93^{A}\pm2.25$	$1.03^{D}\pm0.09$
S3	$31.45^{A}\pm1.88$	$13.37^{A}\pm3.56$	$2.07^{BC}\pm0.26$
S4	$31.05^{A}\pm3.69$	$13.43^{A}\pm4.87$	$1.61^{C}\pm0.25$
S5	$32.47^{A}\pm2.81$	$11.74^{A}\pm2.68$	$2.55^{A}\pm0.39$
S6	$32.39^{A}\pm2.20$	$15.47^{A}\pm2.60$	$2.47^{AB}\pm0.08$
S7	$32.95^{A}\pm2.46$	$13.95^{A}\pm3.59$	$1.89^{C}\pm0.34$
S8	$30.59^{A}\pm3.89$	$15.80^{A}\pm4.08$	$1.78^{C}\pm0.25$

553 **S1**: Control, **S2**: LAB, **S3**: LAB+*C. zeylanoides*, **S4**: LAB+*D. hansenii*, **S5**: LAB+*C. zeylanoides*+*D. hansenii*,
554 **S6**: *C. zeylanoides*, **S7**: *D. hansenii*, **S8**:*C. zeylanoides*+*D. hansenii*, **LAB**: Lactic acid bacteria**, $^{A-D}$:** The uppercase
555 within the same column show that the results are not significantly different (p> 0.05) for color properties of
556 sucuk samples

557 **Table 4.** Volatile compounds of the sucuk samples during ripening period (peak area %)

Volatile Compounds	Ripening period (day)																							
	1st								6th									12th						
	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8	S1	S2	S3	S4	S5	S6	S7	S8
Aldehydes																								
Benzaldehyde	0.23	0.24	0.23	0.32	0.47	0.44	0.49	0.43	0.5	0.25	0.31	0.37	0.3	0.49	0.37	0.48	0.43	0.37	0.42	0.26	-	0.34	0.42	0.39
Nonanal	-	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Benzeneacetaldehyde	-	-	-	-	-	0.45	-	-	0.28	-	-	-	-	-	0.63	0.34	0.96	-	-	-	-	0.38	0.3	0.3
Phellandral	-	-	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cuminaldehyde	25.1	47.3	36.9	36.8	12.5	33.2	44	37.2	30.7	24.9	18.1	22	18.6	41.5	32.9	33.4	34.5	16	4.44	6.94	9.69	35.4	31.1	33.9
Alkanes																								
n-Eicosane	-	-	0.48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pentadecane	0.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alkines																								
1-decyne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.57	-	0.25	-	-	-	-	-
1-undecyne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.36	-	-	-	-	0.55
Acids																								
Hexanoic acid	0.17	0.19	-	0.27	-	-	0.17	-	0.18	-	-	0.26	-	-	0.17	0.13	0.17	0.19	0.32	0.19	-	-	0.19	0.18
Butyric acid	0.17	0.28	0.24	-	0.27	-	0.21	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Isovalericacid	-	-	-	-	-	-	-	-	0.48	-	-	-	-	-	0.21	-	0.54	-	0.37	0.38	0.38	0.7	0.62	0.59
Stearic acid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.69
Palmitic acid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.89	-
9-octadecenoic acid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	-
Propionic (Propanoic) acid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.31	-	0.32
Alcohols																		-						
Amyl alcohol	-	0.92	-	-	1.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Hexanol	0.17	0.21	-	-	0.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Benzyl alcohol	-	0.22	0.23	0.33	0.59	0.58	0.44	-	0.49	-	0.47	0.74	1.04	-	-	0.83	0.44	-	-	-	-	0.38	0.64	0.68
Phenethyl alcohol	0.09	-	0.34	-	0.48	0.57	0.17	0.37	0.49	0.21	0.42	0.63	0.25	0.16	0.35	0.58	0.53	0.16	0.44	0.35	0.52	0.75	0.7	0.97
α-methylbenzylalcohol	0.29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	0.34	0.41	-	-	-
1-Phenyl-1-butanol	-	-	-	-	-	-	-	-	-	-	0.78	-	0.71	-	-	-	-	-	-	-	-	-	-	-
Farnesol (E,E-)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.15	-	-	-	-	-
1,3-cyclohexadiene-1-methanol,4-(1-methylethyl)-	-	-	-	-	-	-	-	-	-	0.14	0.14	0.16	-	-	-	-	-	0.13	0.14	0.14	0.19	-	-	-
Esters																								
Anisylformate	0.2	0.19	0.22	0.35	0.63	0.28	0.3	0.23	0.19	-	-	-	-	0.34	0.19	0.18	-	-	-	-	-	-	-	0.21
α,α-dimethyl phenethyl acetate	0.18	-	0.26	-	0.22	-	-	-	-	-	-	0.46	-	-	-	-	-	0.41	-	-	-	-	-	-

Linalyl butyrate	-	-	0.13	-	-	0.24	-	0.19	-	-	0.24	-	-	-	-	0.24	-	-	-	0.26	0.34	0.23	-	-
Terpinyl acetate	-	-	-	0.59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7	-	0.36	0.46	-
Ethyl valerate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.35	0.9	-	-	-	-
Sulphur compounds																								
Methylthiirane	1.94	0.35	1.03	0.79	-	0.65	-	0.91	0.83	-	-	-	1.16	1.05	-	-	1.86	0.7	-	-	-	0.39	0.53	0.57
Thietane	2.99	0.46	0.45	-	0.55	0.75	1.08	3.38	2.65	2.42	1.66	1.53	3.73	3.03	-	2.14	1.49	3.12	3.3	3.65	4.79	0.5	-	1.28
Methyl 2-propenyl disulfide	1.26	1.59	1.47	1.48	1.3	0.75	0.95	1.03	1.13	1.36	1.05	1.14	1.69	1.19	1	0.87	0.75	1.2	1.21	1.12	1.35	0.76	0.84	0.64
di-2-propenyl disulfide	11.4	4.68	8.19	5.1	8.3	5.75	10.9	8.23	6.83	6.5	8.62	11.3	-	10.6	4.79	5.13	7.88	-	6.68	6.57	7.48	4.67	5.66	4.87
N-ethyl-1,3-dithioisoindoline	0.54	0.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N.N'-dimethylthiourea	0.39	0.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Methyl 2-propenyl trisulfide	-	-	-	-	0.37	-	-	-	-	-	-	-	-	-	-	0.23	-	-	0.16	-	-	-	-	-
Diallyldisulphide	0.36	-	0.29	-	0.23	-	-	0.3	-	-	-	-	-	-	-	0.37	0.35	-	0.3	-	-	-	0.26	-
3-(methylthio)-1-propene	-	-	-	2.46	-	1.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Allyl methyl sulfide	-	-	-	-	-	0.49	0.4	0.64	0.54	0.43	1.2	-	0.32	0.55	0.56	0.42	-	-	-	-	0.81	-	-	-
3,3'-thiobis-1-propene	2.17	2.65	2.63	-	1.8	-	1.9	1.8	1.92	2.38	1.7	2.32	2.63	2.74	1.73	2.07	1.65	-	3.4	-	-	1.9	2.26	-
2.5-dimethylthiazole	-	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3.4-dihydro-3-vinyl-1,2-dithiin	-	0.35	-	0.28	-	-	0.42	0.29	0.26	-	-	-	-	-	-	0.25	-	-	-	-	-	-	-	-
3-vinyl-1,2-dithiacyclohex-4-ene	0.44	0.33	0.3	-	-	-	-	-	0.29	-	-	-	-	0.36	-	-	-	-	-	-	-	-	-	-
2-vinyl-1,3-dithiane	4.09	-	6.06	5.95	3.2	3.31	5.1	4.32	5.83	5.09	4.25	4.97	7.66	4.5	4.72	4.39	5.46	3.97	3.4	3.51	-	3.64	2.67	3.39
2-vinyl-4H-1,3-dithiin	-	-	-	0.35	0.27	-	0.29	-	-	-	-	-	-	-	0.26	-	-	-	-	-	-	-	-	-
1-oxa-4,6-diazacyclooctane-5-thione	1.04	-	-	-	1.16	1.29	0.66	0.89	0.78	1.87	-	1.16	1.25	1.01	1.07	-	0.97	0.62	0.59	0.58	0.85	1.31	1.18	-
5-methyl-1,2,3,4-tetrathia-cyclohexane	0.32	-	-	-	-	-	-	-	-	-	-	-	-	0.32	-	-	-	-	-	-	-	-	-	-
3,4-dimethoxy-1,2,5-thiadiazole	-	-	-	-	-	-	-	-	-	-	0.75	-	-	-	-	-	-	-	-	-	-	-	-	-
Terpenes																								
β-pinene	3.13	1.63	5.15	-	5.77	0.41	-	-	0.83	1.07	0.78	-	-	-	0.73	0.71	-	0.87	1.25	1.8	1.15	-	-	0.36
Limonene	2.05	2.49	2.38	0.65	2.4	1.89	1.12	1.53	2.51	2.48	2.61	2.86	3.05	1.59	2.52	2.33	1.49	3.68	4.85	4.77	3.95	2.53	2.68	2.18
γ-terpinene	4.07	4.41	2.03	2.88	6.01	10.5	3.68	7.48	8.55	3.95	11.8	3.4	12.4	3.98	11.1	9.14	8.48	15.9	22	13	18.7	9.07	9.8	8.94
p-cymene	5.46	7.93	9.15	3.55	5.7	12	5.22	7.81	8.93	12.2	14.1	9.36	11.3	7.26	10.1	9.87	9.14	17.2	16.1	13.8	15.7	11.8	12.1	10.5
α-terpinene	0.35	-	0.36	-	-	0.19	-	0.18	0.21	-	0.23	1.35	0.81	0.24	0.89	0.21	-	0.32	0.32	0.31	0.63	0.35	-	0.21
α-amorphene	-	-	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sabinene	-	-	0.58	0.34	-	0.6	-	-	-	-	-	1.14	1.09	-	-	0.48	-	-	1.55	0.82	0.71	-	-	-
Myrcene	0.25	0.22	0.16	-	-	1.64	0.95	1.18	1.85	1.86	2.14	1.55	1.59	1.01	1.83	1.74	1.31	2.37	0.32	0.99	3.04	1.95	1.97	1.73
delta-3-carene	4.23	8.19	4.79	7.26	6.38	1.74	-	-	1.89	-	1.61	-	-	-	1.84	1.63	-	2.42	2.82	3.12	2.85	1.98	1.7	1.55
α-phellandrene	0.48	0.88	1.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.66	3.44	2.96	-	-	-
Terpinolene	0.23	0.22	0.45	0.31	0.49	0.25	-	0.5	0.5	-	1.11	0.26	0.93	0.2	0.21	0.69	0.34	0.3	0.49	0.86	0.36	0.26	0.23	0.26

Linalol	0.57	0.92	-	0.29	0.58	0.91	0.54	0.78	0.94	0.98	1.02	0.84	1.1	0.67	0.99	0.94	0.63	1.26	1.45	1.4	1.18	0.85	0.94	0.83
Copaene	0.41	0.28	-	-	0.41	0.66	0.33	0.44	0.66	-	0.6	-	0.61	0.4	0.6	0.6	0.51	0.77	0.78	0.74	0.84	0.6	0.65	0.65
α-terpineol	0.16	0.22	0.21	-	-	-	0.19	-	-	-	-	-	-	-	0.25	-	-	-	-	0.28	-	-	0.26	0.27
Valencene	0.24	0.79	-	-	0.61	0.39	0.36	-		0.36		0.5	0.39	0.44	0.4		-	0.38	0.33	0.3	0.35	0.32	0.59	0.39
β-caryophyllene	1.82	2.12	1.33	1.05	1.56	3.15	1.94	2.57	3.29	2.72	3.4	4.29	3.2	2.15	3.24	3.65	2.57	3.75	4.78	4.47	3.95	3.08	2.88	3.44
p-cymenene	-	-	-	0.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Camphene	-	-	-	-	-	0.25	-	0.45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
α-selinene	-	-	-	-	-	0.15	0.14	0.15	0.15	0.15	0.17	0.22	0.16	0.19	0.15	0.17	0.12	0.2	0.15	0.17	0.17	0.17	0.16	0.17
Styrene	-	-	-	-	-	-	0.73	0.84	-	-	-	-	-	-	-	-	-	-	-	-	0.89	-	-	-
Pulegone	1.26	-	-	-	-	-	-	-	-	-	-	-	-	0.38	-	-	-	-	-	-	-	-	-	-
α-copaene	0.39	-	-	-	-	-	-	-	0.6	0.56	-	0.71	-	0.37	0.49	-	0.55	-	-	-	0.74	-	-	-
α-pinene	0.6	-	-	-	0.81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
β-selinene	0.29	0.29	0.3	-	-	0.41	0.35	0.4	-	-	-	-	-	0.37	0.33	0.44	0.29		-	-	-	0.4	0.3	0.36
1,2-dimethoxy-4- benzene	0.21	0.26	0.24	0.29	0.25	0.27	0.19	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,2-dimethoxy-4-(2-propenyl)-benzene	0.24	0.2	0.28	0.26	0.38	0.22	0.27	0.24	0.21	0.26	0.24	0.29	0.25	0.27	0.19	0.22	0.2	0.24	0.17	0.18	0.25	0.3	0.24	0.29
Safranal	5.66	5.7	5.96	6.64	6.97	6.51	6.32	6.12	5.12	4.86	4.28	3.26	3.33	5.76	6.34	6.22	4.93	3.53	1.58	1.88	2.12	5.58	4.13	6.37
β-elemene	-	-	-	-	-	-	-	-	-	-	0.17	-	-	-	-	0.16	-	0.13	0.14	0.12	-	-	-	-
trans-β-farnesene	-	-	-	-	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-
1,3-bis- (1,1-dimethylethyl)-benzene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.29	0.23	0.33	-	-	-	-
Bisabolene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.17	-	-	-	-	-	-	-
Aromatic hydrocarbons																								
Eugenol	0.26	0.53	0.62	6.77	0.52	1	0.7	0.78	1.52	0.83	1.04	0.68	1.07	0.54	0.64	0.66	0.76	0.54	0.55	0.58	0.88	0.88	0.96	1.03
Carvacrol	0.81	2.09	2.41	2.87	1.05	4.22	3.40	3.49	9.00	8.00	8.80	11.40	4.39	2.91	3.55	4.01	8.15	6.52	7.11	6.83	3.71	3.48	3.70	4.78
Naphthalene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-	0.26
Others																								
trans-anethole	-	0.13	0.16	0.19	-	-	0.15	0.14	0.13	0.16	0.12	-	0.15	0.17	-	0.12	-		0.15	-	-	-	-	0.14
α-phellandrene epoxide	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-	-
1,4-dioxan-2-yl hydroperoxide	0.43	-	-	-	-	-	0.48	-	-	-	0.21	-	-	0.36	-	-	-	-	-	-	-	-	-	-

S1: Control, **S2**: LAB, **S3**: LAB+*C. zeylanoides*, **S4**: LAB+*D. hansenii*, **S5**: LAB+*C. zeylanoides*+*D. hansenii*, **S6**: *C. zeylanoides*, **S7**: *D. hansenii*, **S8**:*C. zeylanoides*+*D. hansenii*, **LAB**: Lactic acid bacteria

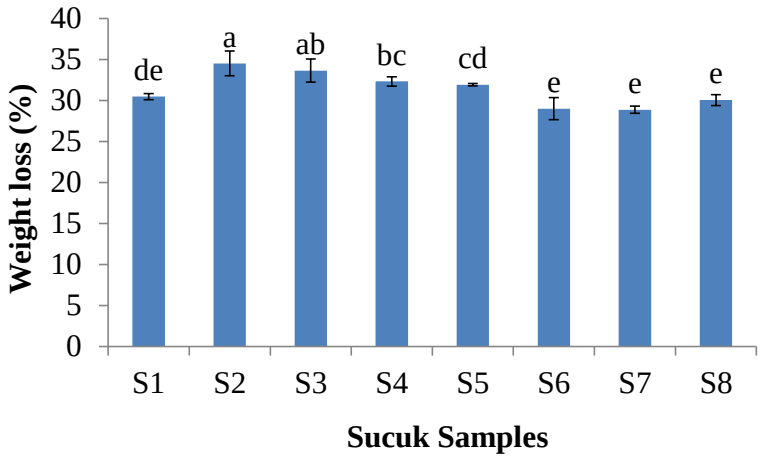

Figure 1. Weight loss (%) of the ripened sucuk samples
S1: Control, **S2**: LAB, **S3**: LAB+*C. zeylanoides*, **S4**: LAB+*D. hansenii*, **S5**: LAB+*C. zeylanoides*+*D. hansenii*, **S6**: *C. zeylanoides*, **S7**: *D. hansenii*, **S8**:*C. zeylanoides*+*D. hansenii*, **LAB**: Lactic acid bacteria, $^{a-e}$: Different lowercase indicate the statistical difference ($p<0.05$) for weight loss of sucuk samples

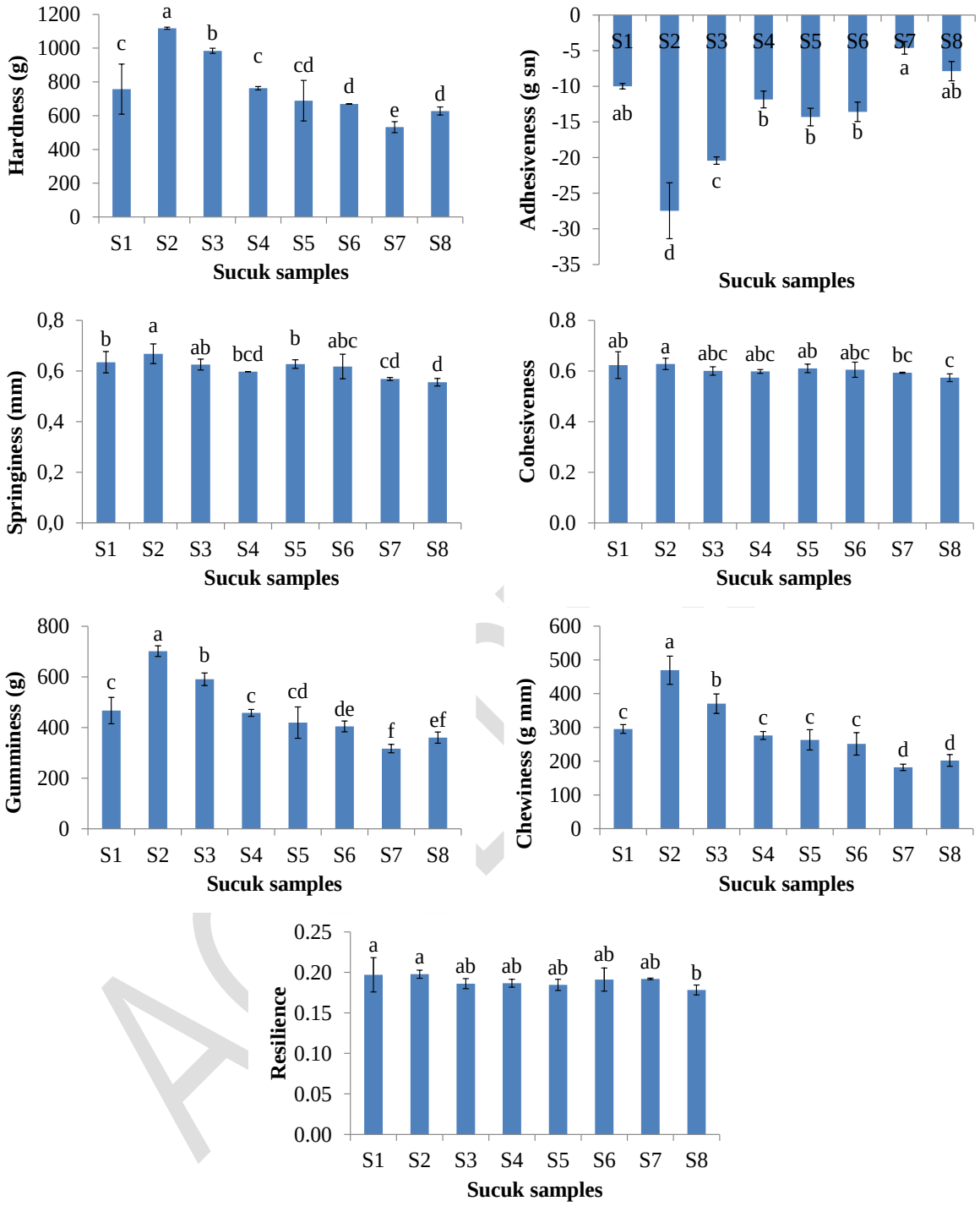

Figure 2. Textural properties of the sucuks produced with yeast cultures

S1: Control, **S2**: LAB, **S3**: LAB+*C. zeylanoides*, **S4**: LAB+*D. hansenii*, **S5**: LAB+*C. zeylanoides*+*D. hansenii*, **S6**: *C. zeylanoides*, **S7**: *D. hansenii*, **S8**:*C. zeylanoides*+*D. hansenii*, **LAB**: Lactic acid bacteria, **[a-f]**: Different lowercase for each parameters indicate the statistical difference ($p<0.05$) for textural properties of sucuk samples.