Effects of NaCl substitution with KCl on quality properties of heat-treated sucuk during the production stages

GÜZIN KABAN – FAZILET BAYRAKTAR – RAHIMEH JABERI – KÜBRA FETTAHOGLU – MÜKERREM KAYA

Summary

In the study, the effects of the degree of NaCl substitution by KCl (NaCl-KCl combinations of 100 : 0, 75 : 25, 50 : 50, 25 : 75, 0 : 100) on microbiological and physico-chemical properties of heat-treated sucuk were investigated during production stages. In addition, the final product was analysed for sensory properties. NaCl-KCl combination, production stage and interactions of these two factors showed very important effects ($P < 0.01$) on water activity, pH and thiobarbituric acid reactive substances, as well as lactic acid bacteria and *Micrococcus* or *Staphylococcus*. The production stage had very significant ($P < 0.01$) effect on L^*, a^* and b^* values, while NaCl-KCl combination had no effect on colour values. By sensory analysis, it was determined that odour and taste scores decreased considerably in the case of using only KCl (100 %; $P < 0.01$). The combinations of 25 : 75 and 0 : 100 showed lower values than the control group (100 : 0) in terms of texture and general acceptability scores. Principal component analysis was also applied to determine relation the between NaCl-KCl combination and sensory properties. The results of the study showed that 50 % of NaCl could be replaced with KCl in the production of heat-treated sucuk.

Keywords

heat-treated sucuk; KCl; NaCl; sensorial properties; principal component analysis

Sodium chloride (NaCl) is the major source of sodium, one of the essential elements in the human body, in food. In recent decades, the concern about high sodium intake has increased [1]. The excessive intake of sodium is a reason of health problems, playing an essential role in emergence of many diseases such as hypertension, cardiovascular diseases, gastritis, cancer, osteoporosis and kidney diseases [2, 3].

Sodium is naturally found in many foods, but most of the sodium in the diet comes from processed foods [4]. However, NaCl is an indispensable and multifunctional ingredient in meat processing. An important function of NaCl used in production is to give the product the typical taste and flavour. In addition, it also prevents the growth of undesirable microorganisms as it lowers the water activity value [2, 4]. On the other hand, NaCl limits bacterial growth due to the toxic effect of the chloride anion. Despite these functions, efforts are made by the food industry to reduce the content of NaCl in food products to help to reduce the negative effects of excessive sodium consumption on health [5]. One of the options is to substitute NaCl with a certain amount of other salts such as potassium chloride (KCl), magnesium chloride ($MgCl_2$) or calcium chloride ($CaCl_2$) in production [6, 7]. The use of KCl in salt mixtures can be beneficial by reducing the harmful effect of sodium on blood pressure because potassium is the counter-ion of sodium [8]. KCl and NaCl have similar antimicrobial functional properties [9]. On the other hand, the use of KCl can reduce the salty taste and promote a bitter and metallic taste in products [7, 10, 11]. Moreover, the partial substitution or reduction of NaCl content in meat products does not only cause changes in the acceptability of the final product, but also affects the safety of the product. Therefore, it is necessary to use an optimum amount of NaCl with KCl to

Güzin Kaban, Fazilet Bayraktar, Rahimeh Jaberi, Mükerrem Kaya, Department of Food Engineering, Faculty of Agriculture, Atatürk University, Prof. Dr. Ertugrul Hursit Street No. 4, 25050 Erzurum, Turkey.
Kübra Fettahoglu, Dogubayazit Ahmed-i Hani Vocational School, Agri Ibrahim Cecen University, Ishakpasa Sarayi Street, 04400 Agri, Dogubayazit, Turkey.

Correspondence author:
Güzin Kaban, tel.: +90 442 231 2425, fax: +90 442 236 09 58, e-mail: gkaban@atauni.edu.tr

improve the product's taste and to extend the shelf life and safety of the product [2].

Heat-treated sucuk, a semi-dry fermented sausage type, is one of the most widely produced meat products in Turkey [12]. This type of sausage, like other fermented sausages, is a source of sodium in nutrition. However, no studies have been carried out to reduce the salt content of this product. For this reason, we evaluated the possibility of substituting a portion of NaCl by KCl in the production of heat-treated sucuk. Heat-treated sucuk was prepared using five different NaCl-KCl combinations (100 : 0 – control, 75 : 25, 50 : 50, 25 : 75 and 0 : 100). The samples were taken from certain production stages (sucuk batter, after fermentation, after heat treatment and after drying), and subjected to microbiological analysis (quantification of lactic acid bacteria, *Micrococcus* plus *Staphylococcus* and Enterobacteriaceae) and physico-chemical analysis (determination of water activity, pH, thiobarbituric acid reactive substances and instrumental colour parameters). In addition, the final product was evaluated regarding sensory properties.

MATERIAL AND METHODS

Materials

Beef meat obtained from the chuck and round at 24 h post mortem, beef fat (subcutaneous and intermuscular fat) and sheep tail fat used in the study were obtained from the Meat and Dairy Institution Erzurum Meat Slaughterhouse (Erzurum, Turkey). Beef meat, beef fat and sheep tail fat were cut into small pieces and stored at –20 °C until production for a maximum of two days. Autochthonous *Lactobacillus sakei* S15 [13] and *Staphylococcus xylosus* GM92 [14] strains were used as a starter culture. Before use of starter culture in production, *Lb. sakei* was grown in de Man, Rogosa and Sharpe broth (MRS; Merck, Darmstadt, Germany) and *Staph. xylosus* was grown in tryptic soy broth (TSB, Merck) broth for 24 h at 30 °C without shaking.

Heat-treated sucuk production

In the production, per 1 kg of the meat-fat mixture (80 % lean meat, 10 % beef fat and 10 % sheep tail fat), the following were used: 10 g garlic, 4 g saccharose, 7 g red pepper, 5 g black pepper, 9 g cumin, 2.5 g pimento and 0.15 g sodium nitrite. Also, five salt mixes were prepared based on five different NaCl-KCl (chemical purity from Merck) combinations (100 : 0 – control, 75 : 25, 50 : 50, 25 : 75 and 0 : 100, weight-based). From each salt mixture, 20 g salt per kilogram of beef meat and fat mixture was used in the production. *Lb. sakei* S15 and *Staph. xylosus* GM92 were inoculated into the sucuk batter at approximately 10^7 CFU·g^{-1} and 10^6 CFU·g^{-1}, respectively. A laboratory cutter MTK 662 (Mado, Dornhan, Germany) was used for preparation of heat-treated sucuk. Each batter was stuffed into collagen casings (diameter 38 mm; Naturin Viscofan, Weinheim, Germany) with a laboratory-type filling machine MTK 591 (Mado). After filling, the samples were kept in a controlled climate chamber (Reich Thermoprozestechnik, Schechingen, Germany) in which temperature, airflow and relative humidity were automatically controlled. For each treatment (4 kg of beef + 1 kg of fat), two batters were prepared. Thus, a total of 10 batters and 200 sucuk samples were obtained. The fermentation process was carried out at 22 ± 1 °C and 90 ± 2 % relative humidity for 24 h. Following the fermentation process, the samples were taken to the cooking chamber (Mauting, Valtice, Czech Republic). Heat treatment was applied starting from 40 °C until an internal temperature of 68 °C was reached. Following this process, the samples were taken to the controlled climate chamber and dried at 16 ± 1 °C and 80 ± 2 % relative humidity for 3 days.

Sampling

The production was twice for each treatment. Two random samples were taken from each production stage (batter, fermentation, heat treatment and drying (final product)) and were analysed. Sensory analysis was performed only for the final product.

Microbiological analysis

A 25 g sample was added to 225 ml physiological saline (8.5 g·l^{-1} NaCl) and homogenized in a homogenizer Lab Stomacher Blender 400-BA (Seward Medical, London, United Kingdom) for 1 min. Decimal dilutions were prepared from the homogenate. For quantification of lactic acid bacteria, MRS agar (Merck) was used, incubation being carried out at 30 °C for 48 h under anaerobic conditions (Anaerocult A, Merck). Mannitol salt phenol red agar (MSA, Merck) was used for quantification of *Micrococcus* and *Staphylococcus*, the plates being incubated aerobically at 30 °C for 48 h. For quantification of Enterobacteriaceae, violet red bile dextrose agar (VRBD, Merck) was used, the plates being incubated aerobically at 30 °C for 48 h.

Water activity and pH

The water activity (a_W) value of the samples was determined using the device TH-500 a_w Sprint (Novasina, Lachen, Switzerland), which had been previously calibrated with calibration salts. Measurements were carried out at 25 °C in duplicate. The pH values of the samples were measured, after homogenizing 10 g of sample in 100 ml of distilled water, by a pH-meter with a glass electrode (Mettler-Toledo, Columbus, Ohio, USA).

TBARS analysis

For determination of thiobarbituric acid reactive substances (TBARS) values, the method of Kilic and Richards [15] was used. An amount of 2 g of the sample was mixed with 12 ml trichloroacetic acid solution (7.5% trichloroacetic acid, 0.1% ethylene diamine tetraacetic acid, 0.1% propyl gallate) and homogenized. The homogenate was filtered through a Whatman filter paper grade 1 (Merck), 3 ml of filtrate was added to 0.02 $mol \cdot l^{-1}$ thiobarbituric acid solution. The mixture was kept in a boiling water bath for 40 min. Then, centrifugation was applied for 5 min at 2 000 $\times g$ (Centrifuge MR23G, Thermo Fisher Scientific, Waltham, Massachusetts, USA). Finally, the absorbance was determined at 530 nm. TBARS value was expressed as micromoles of malondialdehyde (MDA) per kilogram of sample.

Colour analysis

The values of L^* (lightness), a^* (red-green component) and b^* (yellow-blue component) in sliced samples were determined using Konica Chroma CR-400 with a *C D65 illuminant, an aperture size of 8 mm and standard observation angle of 2° (Minolta, Osaka, Japan). Measurements were performed in triplicate.

Sensory evaluation

The sensory analysis was carried out by 22 trained panelists. Panel members were selected from the staff, the members of the Department of Food Engineering (Atatürk University, Erzurum, Turkey). The sensory characteristics were evaluated using a structured 9-point hedonic scale. The panelists were asked to evaluate the following parameters: colour (9 – brownish red, 1 – light pale), texture (9 – very good, 1 – very bad), taste (9 – very good, 1 – very bad), odour (9 – typical heat-treated sucuk taste and aroma, 1 – no typical heat-treated sucuk taste and aroma) and overall acceptability (9 – very good, 1 – very bad). Samples were sliced to be approximately 1 cm thick, and one portion from each sample unit was randomly selected and served to the panelists for evaluation at room temperature. Two replicates per treatment were tested following a completely randomized design with two samples per plate. Water and bread were provided between samples. Each sample was separately assessed in two independent repetitions by an expert panel. The 44 individual results were taken into consideration for the assessment of each trait.

Statistical analysis

NaCl-KCl combination (100 : 0, 75 : 25, 50 : 50, 25 : 75 and 0 : 100) and production stage (sucuk batter, after fermentation, after heat treatment and after drying) were considered as factors in the study. The experiment was replicated two times and carried out in 5 × 4 factorial design according to a completely randomized design. The obtained data were subjected to two-way ANOVA using a general linear model. Duncan's multiple range test was used for comparing the means to find out the effects of NaCl-KCl combination and production stage on various parameters at $P < 0.05$. The statistical analysis was performed using SPSS version 20 statistical program (IBM SPSS; Chicago, Illinois, USA). Principal component analysis (PCA) was performed using Unscrambler version 10.1 (Camo Software, Oslo, Norway) to determine the relationship between NaCl-KCl combination and sensory properties.

RESULTS AND DISCUSSION

The degree of NaCl substitution by KCl (i.e. NaCl-KCl combination) and production stage had a very significant effect on counts of lactic acid bacteria as well as on *Micrococcus* and *Staphylococcus* in heat-treated sucuk ($P < 0.01$; Tab. 1). In the production, as *Lb. sakei* S15 was used as a starter culture, the initial content of lactic acid bacteria in all treatments was approximately 7 log $CFU \cdot g^{-1}$. These counts were above 8 log $CFU \cdot g^{-1}$ at the end of fermentation. A decrease in the counts of lactic acid bacteria was observed in heat treatment and drying stages (Tab. 1). However, heat treatment and drying stages caused differences between the groups. The lowest number of lactic acid bacteria was determined in NaCl-KCl combination of 50 : 50 after heat treatment. After the drying stage, 50 : 50 and 75 : 25 NaCl-KCl combinations showed lower numbers than the other treatments (Fig. 1). These results are in accordance with the observation reported in many studies that changing the NaCl content in fermented sausages has no significant effect on the content of lactic acid bacteria [16–18].

Tab. 1. Effects of NaCl-KCl combination and production stage on microbiological and physico-chemical properties of heat-treated sucuk.

NaCl-KCl combination	Lactic acid bacteria [log CFU·g^{-1}]	*Micrococcus* and *Staphylococcus* [log CFU·g^{-1}]	a_w	pH	TBARS [µmol·kg^{-1}]	L^*	a^*	b^*
100 : 0	6.02 ± 1.81^{b}	4.85 ± 1.34^{ab}	0.958 ± 0.012^{b}	5.41 ± 0.24^{b}	6.35 ± 1.72^{c}	46.52 ± 6.49^{a}	14.28 ± 3.57^{a}	15.68 ± 3.11^{a}
75 : 25	5.99 ± 1.81^{b}	4.64 ± 1.26^{d}	0.956 ± 0.014^{c}	5.44 ± 0.23^{a}	7.20 ± 1.89^{b}	46.22 ± 4.76^{a}	14.48 ± 3.08^{a}	15.74 ± 3.15^{a}
50 : 50	5.84 ± 1.89^{c}	4.72 ± 1.31^{c}	0.957 ± 0.012^{b}	5.40 ± 0.28^{bc}	7.53 ± 1.48^{b}	45.63 ± 5.40^{a}	14.92 ± 3.04^{a}	16.26 ± 3.02^{a}
25 : 75	6.06 ± 1.74^{b}	4.89 ± 1.28^{a}	0.960 ± 0.010^{a}	5.38 ± 0.29^{c}	8.17 ± 1.62^{a}	46.55 ± 4.75^{a}	13.83 ± 3.35^{a}	15.72 ± 2.95^{a}
0 : 100	6.26 ± 1.68^{a}	4.81 ± 1.24^{b}	0.961 ± 0.012^{a}	5.30 ± 0.30^{d}	7.64 ± 2.51^{b}	46.87 ± 6.12^{a}	14.18 ± 3.32^{a}	16.59 ± 3.02^{a}
Significance	**	**	**	**	**	NS	NS	NS
Production stage								
Sucuk batter	7.29 ± 0.12^{b}	5.83 ± 0.11^{b}	0.973 ± 0.002^{a}	5.81 ± 0.04^{a}	4.67 ± 0.90^{c}	43.89 ± 4.28^{b}	9.43 ± 1.62^{b}	20.45 ± 2.21^{a}
After fermentation	8.16 ± 0.09^{a}	6.19 ± 0.22^{a}	0.960 ± 0.003^{b}	5.13 ± 0.07^{d}	8.12 ± 0.67^{b}	40.07 ± 3.42^{c}	16.41 ± 2.23^{a}	15.35 ± 1.48^{b}
After heat-treatment	4.56 ± 0.34^{c}	3.70 ± 0.19^{c}	0.961 ± 0.002^{b}	5.27 ± 0.06^{c}	7.87 ± 1.01^{b}	51.25 ± 1.59^{a}	15.74 ± 1.05^{a}	14.18 ± 1.04^{c}
After drying	4.14 ± 0.23^{d}	3.41 ± 0.12^{d}	0.941 ± 0.004^{c}	5.34 ± 0.08^{b}	8.86 ± 1.53^{a}	50.21 ± 1.78^{a}	15.77 ± 0.91^{a}	14.01 ± 0.94^{c}
Significance	**	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	NS	NS

Any two means in the same column having the same letters in superscript in the same section are not significantly different at $P > 0.05$.
Significance: ** – $P < 0.01$, * – $P < 0.05$, NS – not significant. Interaction: the effect of NaCl-KCl combination and production stage.
TBARS – thiobarbituric acid reactive substances (expressed as micromoles of malondialdehyde per kilogram of sample).

In the production, *Staph. xylosus* GM92 was added to the batter at about 6 log CFU·g^{-1}. After 24 h of fermentation, there was a slight increase in the counts of *Micrococcus* and *Staphylococcus*. In the heat treatment and drying stages, the content of *Micrococcus* and *Staphylococcus* decreased, and the lowest mean content was determined in the drying stage (Tab. 1). The strain of *Staph. xylosus* GM92 showed a good growth in 100 : 0 NaCl-KCl group. However, it was more affected by heat-treatment than other groups and the greatest decrease was determined in this group (Fig. 2). The growth of *Micrococcus* and *Staphylococcus* in the 75 : 25 NaCl-KCl treatment showed a lower growth rate compared to other treatments. In the heat-treatment application, the highest counts of *Micrococcus* and *Staphylococcus* were determined in the group with 25 : 75 NaCl-KCl (Fig. 2). Gimeno et al. [17] stated that the members of Micrococcaceae are sensitive to acid so their growth during ripening was slower in the sausage (NaCl 10 g·kg^{-1}, $MgCl_2$ 2.35 g·kg^{-1}, KCl 5.52 g·kg^{-1} and CaCl2: 4.64 g·kg^{-1}) than control group (NaCl 26 g·kg^{-1}), due to stronger acidification. However, it was reported that different chloride salts substituted for NaCl had no effect on the counts of Micrococcaceae [18, 19]. In contrast, Gelabert et al. [16] found that substitution of NaCl with 40 % KCl in the the product caused an increase in the counts of Micrococcaceae.

The counts of Enterobacteriaceae remained below the detectable limit (10^2 CFU·g^{-1}) in all treatments in heat-treated sucuk during production stages. Similarly, it has been reported that the counts of Enterobacteriaceae decrease due to the decrease in pH and water activity during the ripening [20].

The used NaCl-KCl combination had a very significant effect ($P < 0.01$) on a_w value in the production of heat-treated sucuk (Tab. 1). Zanardi et al. [21] stated that decreasing the NaCl ratio affects the water retention capacity of proteins and the drying process. As in this study, Gelabert et al. [16] observed that NaCl causes a greater decrease in water activity compared to KCl. Also, replacing NaCl with other salts leads to products with a higher water activity [22]. Similarly, Ibanez et al. [23] stated that partial substitution of NaCl by KCl or reduction of NaCl content could affect the drying process of dry fermented sausage and this situation causes to higher a_w value. However, in a study

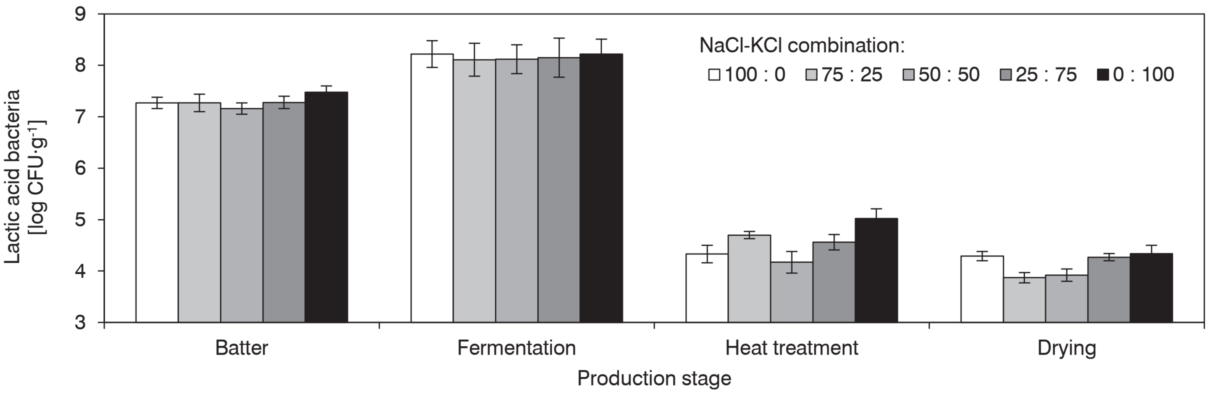

Fig. 1. Effects of NaCl-KCl combination and production stage interaction on counts of lactic acid bacteria in heat-treated sucuk.

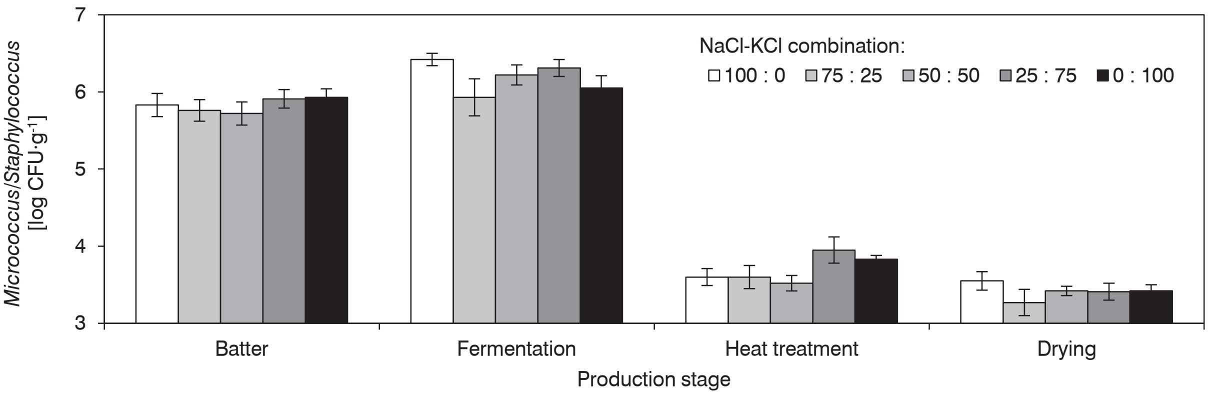

Fig. 2. Effects of NaCl-KCl combination and production stage interaction on *Micrococcus* and *Staphylococcus* counts in heat-treated sucuk.

on fermented cooked sausages, Dos Santos et al. [24] reported that the use of 50 % and 75 % KCl instead of NaCl did not affect the drying process. In the present study, the mean a_W value was determined as 0.941 after drying. However, the interaction was significant ($P < 0.01$; Tab. 1). After drying, groups with high KCl levels (25 : 75 and 0 : 100 NaCl-KCl) showed higher a_W values than other groups (data not shown). This phenomenon can be explained by the fact that potassium could react with muscle surface proteins to prevent sodium penetration. The drying rate of the sausages is slow due to the use of high KCl, resulting in higher a_W [10].

The NaCl-KCl combination had a very significant effect on pH value of the heat-treated sucuk. The lowest mean pH value was determined in a sample with 0 : 100 NaCl-KCl combination (Tab. 1). Similar results were previously reported for fermented cooked sausages [21, 22] and a dry fermented sausage [25]. In contrast, Campagnol et al. [19] stated that the use of KCl did not cause a significant change in the pH value. In the study, the production stage had a significant effect on pH value. The lowest pH value was determined after fermentation and the pH value increased in the heat treatment and in drying processes. In all treatments, pH value decreased due to lactic acid formation during fermentation and increased because of protein denaturation during heat treatment [12, 13]. Proteolysis caused an increase in pH value on the drying stage. The interaction of salt combination and production stage in the heat-treated sucuk had a very significant effect on pH value ($P < 0.01$; Tab. 1). After fermentation, samples with 0 : 100 NaCl-KCl showed lower pH value than samples with other combinations. Similar results were obtained for other stages (data not shown).

The NaCl-KCl combination and production stage had a very significant effect ($P < 0.01$) on TBARS value in the production of heat-treated sucuk (Tab. 1). ZANARDI et al. [21] reported that using salt mixtures (NaCl, KCl, $MgCl_2$ and $CaCl_2$) in fermented sausage led to higher TBARS values than the control (NaCl). ORDONEZ et al. [26] also stated that the use of KCl reduced oxidation in dry-fermented sausages but its use is limited due to the release of a bitter taste. On the other hand, it was reported that partial substitution of NaCl with 30 %, 50 %, and 70 % of KCl had no significant effect on TBARS value in Chinese bacon [27].

In contrast, KCl could act as a pro-oxidant by inhibiting antioxidant enzyme activities in meat [3]. In the current study, it was found that substitution of a part of NaCl by KCl increased lipid oxidation. On the other hand, it was previously reported that NaCl had a significant pro-oxidant effect on meat and meat products and accelerated lipid oxidation [21]. In this study, TBARS values increased during fermentation and decreased after heat treatment (Tab. 1). However, the difference between these two stages was found statistically insignificant ($P > 0.05$). In other studies, it was reported that TBARS value increased during the progress of ripening [12, 13].

The salt combination used and the production stage had a very significant effect on TBARS value ($P < 0.01$). The lowest TBARS value of sucuk batter was determined in 100 : 0 NaCl-KCl treatment. The combination of 25 : 75 NaCl-KCl, which had the highest TBARS value in sucuk batter, showed a lower increase during fermentation than other treatments. In the current study, TBARS values of the control (100 : 0 NaCl-KCl), 75 : 25 NaCl-KCl and 50 : 50 NaCl-KCl treatments decreased during heat treatment. There was an increase in the groups containing 25 : 75 NaCl-KCl and 0 : 100 NaCl-KCl. During drying, TBARS values increased in all treatments, but this increase was observed mostly in the group containing 0 : 100 NaCl-KCl (Fig. 3). According to these results, the rate of KCl use appears to be a factor that should be evaluated also regarding lipid oxidation. The different levels of NaCl substitution by KCl had no significant effect on L^*, a^* and b^* values ($P > 0.05$), while the production stage had a significant effect on colour values ($P < 0.01$; Tab. 2). DOS SANTOS et al. [24] and CAMPAGNOL et al. [22] also reported that the use of 50 % KCl instead of NaCl had no significant effect on L^*, a^* and b^* values of fermented cooked sausages. In contrast, GIMENO et al. [28] reported that partial replacement of NaCl increased L^* and b^* value and had no significant effect on a^* value. DOS SANTOS et al. [29] stated that using 50 % KCl had no significant effect on L^* and b^* values, but it statistically affected a^* value. On the other hand, TEIXERIA et al. [30] reported that NaCl replacement only influenced the L^* value of bisaro pork sausage samples, while ripening time changed all colour parameters.

In the study, L^* value decreased during the fermentation process and increased after heat treatment. After fermentation and heat treatment, statistical difference was determined and the highest L^* value was observed after heat treatment. However, this value was not found statistically significantly different from the value determined during the drying process (Tab. 1). The a^* value, which is the indicator or redness, showed the lowest value in the heat-treated sucuk batter. After fermentation, a^* value increased in contrast to L^* and b^* values. The a^* value increased as a result of the heat treatment application but this increase did not differ statistically from the mean values determined in both fermentation and dry-

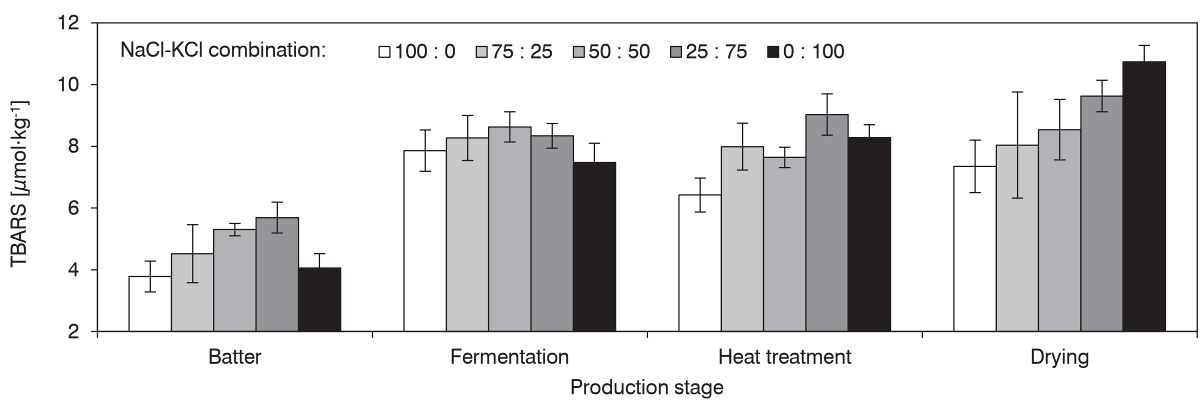

Fig. 3. Effects of NaCl-KCl combination and production stage interaction on TBARS value of heat-treated sucuk.
TBARS – thiobarbituric acid reactive substances (expressed as micromoles of malondialdehyde per kilogram of sample).

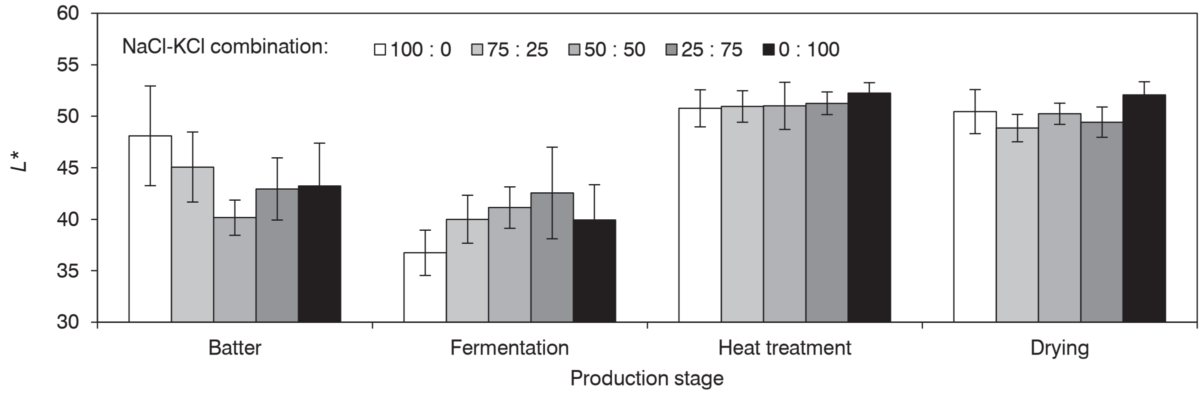

Fig. 4. Effects of NaCl-KCl combination and production stage interaction on *L** value of heat-treated sucuk.

ing stages. The *b** value, which is a measure of the intensity of yellow colour, showed the highest value in the sucuk batter. In the later stages of production, a continuous decrease was found in the *b** value. Ercoskun et al. [31] reported that heat treatment application caused an increase in *L**, *a** and *b** values in sucuk samples. However, in the present study, heat treatment only increased the *L** value.

The interaction of NaCl-KCl combination and production stage had a very significant effect ($P < 0.01$) on *L** value of the heat-treated sucuk (Tab. 1). The 100 : 0 NaCl-KCl treatment had the highest *L** value in the sucuk batter. However, *L** value decreased significantly during fermentation in these samples. Control treatment also showed a significant increase during heat treatment as in other groups (Fig. 4). This situation was due to the formation of nitroso-hemochrome, which is a bright reddish colour pigment, during heat treatment [32]. During the drying stage, there was no significant change in the *L** value in the 0 : 100 NaCl-KCl treatment.

The sensory analysis results of heat-treated sucuk produced with various NaCl-KCl combinations are shown in Tab. 2. The different levels of KCl had a very significant effect ($P < 0.01$) on texture and taste, together with a significant effect on odour and general acceptability of the products ($P < 0.05$). A decrease was observed in sensory quality as the KCl content in the heat-treated sucuk formulation increased (Tab. 2). The partial substitution of NaCl by KCl mostly has a negative effect on flavour and texture of the product [33]. The use of KCl had no significant effect on colour in terms of sensory evaluation ($P > 0.05$). Many researchers emphasized that the use of KCl at a proportion higher than 40–50 % significantly reduces sensory quality [7, 10, 34]. In the present study, the panelists stated that samples containing 0 : 100 NaCl-KCl had a bitter taste, which was in concordance with other studies [24, 34]. In a study on substitution of NaCl by KCl in a sausage, it was determined that the salty taste was lower compared to the control group. However, it was stated that it is possible to use 23 % of KCl and a lactate

Tab. 2. Overall effects of NaCl-KCl combination and production stage on sensory properties of heat-treated sucuk.

NaCl-KCl combination	Colour	Texture	Odour	Taste	Acceptability
100 : 0	7.38 ± 0.35 [a]	7.40 ± 0.22 [a]	7.68 ± 0.22 [a]	7.28 ± 0.33 [a]	7.48 ± 0.36 [a]
75 : 25	7.28 ± 0.22 [a]	7.40 ± 0.22 [a]	7.30 ± 0.14 [a]	7.18 ± 0.25 [ab]	7.15 ± 0.60 [ab]
50 : 50	7.38 ± 0.35 [a]	7.13 ± 0.22 [ab]	7.30 ± 0.22 [a]	7.05 ± 0.40 [ab]	6.90 ± 0.58 [ab]
25 : 75	7.85 ± 0.44 [a]	6.85 ± 0.45 [bc]	7.10 ± 0.38 [a]	6.58 ± 0.51 [b]	6.50 ± 0.62 [bc]
0 : 100	7.13 ± 0.22 [a]	6.63 ± 0.17 [c]	6.15 ± 1.15 [b]	5.63 ± 0.48 [c]	6.08 ± 0.32 [c]
Significance	NS	**	*	**	*

Any two means in the same column having the same letters in superscript in the same section are not significantly different at $P > 0.05$.
Significance: ** – $P < 0.01$, * – $P < 0.05$, NS – not significant.

Tab. 3. Eigenvalue scores, variances and their cumulative proportions of the components.

PC	Eigenvalue		Explained variance	
	For PC	Cumulative	For PC	Cumulative
PC1	1.1617	1.1617	91.00	91.00
PC2	0.0994	1.2611	8.00	99.00
PC3	0.0131	1.2742	0.70	99.70
PC4	0.0037	1.2779	0.30	100.00

PC – principal component.

Tab. 4. Eigenvectors of the variance–covariance matrix used for principal component analysis.

	PC1	PC2	PC3	PC4
NaCl-KCl combinations				
100 : 0	1.054	–0.112	–0.164	–0.015
75 : 25	0.626	–0.210	0.103	0.077
50 : 50	0.344	0.026	0.115	–0.087
25 : 75	–0.313	0.533	–0.016	0.029
0 : 100	–1.711	–0.238	–0.037	–0.004
Sensory properties				
Colour	0.047	0.832	0.164	–0.495
Texture	0.301	–0.294	–0.127	–0.713
Odour	0.523	0.313	0.306	0.467
Taste	0.624	0.086	–0.695	0.098
Acceptability	0.494	–0.340	0.616	–0.137

PC – principal component.

salt [7]. Dos Santos et al. [29] stated that the sensory quality decreased with low sodium content in dry fermented sausages, but the use of 50 % KCl, or KCl and $CaCl_2$ (1 : 1), would not be a major problem in commercialization of the samples.

Principal component analysis (PCA) was used to qualitatively differentiate samples based on NaCl-KCl combination and sensory properties. The eigenvalues, variances and their cumulative proportions are shown in Tab. 3, coefficients of first four principal components (PC) are given in Tab. 4. The first four principal components with eigenvalues greater than 1 were analysed. The first PC was enough to explain 91 % of the variation and PC2 accounted for 8 % of the total variance (Tab. 3). In other words, the first two principal components explained 99 % of the total variance. PC1 provided a good separation between all groups (Fig. 5). While groups containing 50 % or more NaCl were placed on the positive side of PC1, the groups with 25 : 75 NaCl-KCl and 0 : 100 NaCl-KCl were located on the negative side of PC1. In addition, all the sensory parameters examined were located on the positive side of PC1. These results showed that there was a high positive correlation between the sensory parameters examined and the groups containing 50 % or more NaCl.

CONCLUSION

The results of the study showed that when using KCl instead of NaCl in the production of heat treated sucuk, an increase in the KCl proportion above 50 % specifically increases TBARS value and decreases pH in heat-treated sucuk in the final product. In case of usage of KCl, L^* value increased in the final product. In addition to these, KCl caused changes in sensory properties, which was also revealed by PCA analysis in this study. As a result, it does not seem possible to use KCl instead of NaCl at a proportion greater than 50 % in

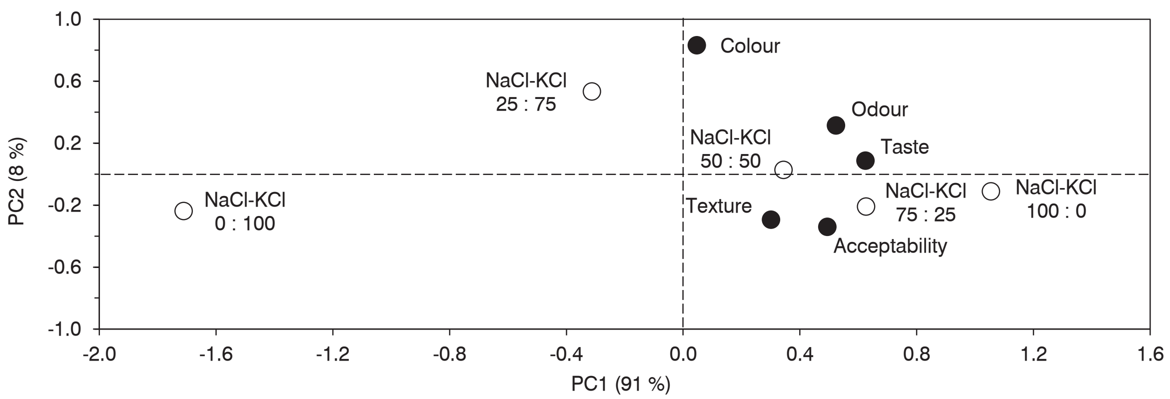

Fig. 5. Principal component analysis biplot of the relationships between NaCl-KCl combination and sensory properties.

heat-treated sucuk, since the sensory properties, in particular the taste, are adversely affected.

REFERENCES

1. Teixeira, A. – Rodrigues, S.: Consumer perceptions towards healthier meat products. Current Opinion in Food Science, *38*, 2021, pp. 147–154. DOI: 10.1016/j.cofs.2020.12.004.
2. Raybaudi-Massilia, R. – Mosqueda-Melgar, J. – Rosales-Oballos, Y. – Citti de Petricone, R. – Fragenas, N. N. – Zambrano-Duran, A. – Sayago, K. – Lara, M. – Urbina, G.: New alternative to reduce sodium chloride in meat products: Sensory and microbiological evaluation. LWT – Food Science and Technology, *108*, 2019, pp. 253–260. DOI: 10.1016/j.lwt.2019.03.057.
3. Wen, R. – Hu, Y. – Zhang, L. – Wang, Y. – Chen, Q. – Kong, B.: Effect of NaCl substitutes on lipid and protein oxidation and flavor development of Harbin dry sausage. Meat Science, *156*, 2019, pp. 33–43. DOI: 10.1016/j.meatsci.2019.05.011.
4. Stanley, R. E. – Bower, C. G. – Sullivan, G. A.: Influence of sodium chloride reduction and replacement with potassium chloride based salts on the sensory and physico-chemical characteristics of pork sausage patties. Meat Science, *133*, 2017, pp. 36–42. DOI: 10.1016/j.meatsci.2017.05.021.
5. Guardia, M. D. – Guerrero, L. – Gelabert, J. – Gou, P. – Arnau, J.: Sensory characterisation and consumer acceptability of small calibre fermented sausages with 50% substitution of NaCl by mixtures of KCl and potassium lactate. Meat Science, *80*, 2008, pp. 1225–1230. DOI: 10.1016/j.meatsci.2008.05.031.
6. Armenteros, M. – Aristoy, M. C. – Barat, C. M. – Toldra, F.: Biochemical and sensory properties of dry-cured loins as affected by partial replacement of sodium by potassium, calcium, and magnesium. Journal of Agricultural and Food Chemistry, *57*, 2009, pp. 9699–9705. DOI: 10.1021/jf901768z.
7. Paulsen, M. T. – Nys, A. – Kvarberg, R. – Hersleth, M.: Effect of NaCl substitution on the sensory properties of sausages: temporal aspects. Meat Science, *98*, 2014, pp. 164–170. DOI: 10.1016/j.meatsci.2014.05.020.
8. Ruusunen, M. – Puolanne, E.: Reducing sodium intake from meat products. Meat Science, *70*, 2005, pp. 531–541. DOI: 10.1016/j.meatsci.2004.07.016.
9. Da Silva, S. L. – Lorenzo, J. M. – Machado, J. M. – Manfio, M. – Cichoski, A. J. – Fries, L. L. M. – Morgano, M. A. – Campagnol, P. C. B.: Application of arginine and histidine to improve the technological and sensory properties of low-fat and low-sodium bologna-type sausages produced with high levels of KCl. Meat Science, *159*, 2020, article 107939. DOI: 10.1016/j.meatsci.2019.107939.
10. Chen, J. – Hu, Y. – Wen, R. – Liu, Q. – Chen, Q. – Kong, B.: Effect of NaCl substitutes on the physical, microbial and sensory characteristics of Harbin dry sausage. Meat Science, *156*, 2019, pp. 205–213. DOI: 10.1016/j.meatsci.2019.05.035.
11. Zhao, B. – Zhou, H. – Zhang, S. – Pan, X. – Li, S. – Zhu, N. – Wu, Q. – Wang, S. – Qiao, X. – Chen, W.: Changes of protein oxidation, lipid oxidation and lipolysis in Chinese dry sausage with different sodium chloride curing salt content. Food Science and Human Wellness, *9*, 2020, pp. 328–337. DOI: 10.1016/j.fshw.2020.04.013.
12. Armutcu, Ü. – Hazar, F. Y. – Yilmaz Oral, Z. F. – Kaban, G. – Kaya, M.: Effects of different internal temperature applications on quality properties of heat-treated sucuk during production. Journal of Food Processing and Preservation, *44*, 2020, article e14455. DOI: 10.1111/jfpp.14455.
13. Yilmaz Oral, Z. F. – Kaban, G.: Effects of autochthonous strains on volatile compounds and quality properties of heat-treated sucuk. Food Bioscience, *43*, 2021, article 101140. DOI: 10.1016/j.fbio.2021.101140.
14. Kaban, G. – Kaya, M.: Effects of *Lactobacillus plantarum* and *Staphylococcus xylosus* on the quality characteristics of dry fermented sausage "sucuk". Journal of Food Science, *74*, 2009, pp. S58–S63. DOI: 10.1111/j.1750-3841.2008.01014.x.
15. Kilic, B. – Richards, M. P.: Lipid oxidation in poultry döner kebab: Pro-oxidative and anti-oxidative factors. Journal of Food Science, *68*, 2003, pp. 686–689. DOI: 10.1111/j.1365-2621.2003.tb05732.x.
16. Gelabert, J. – Gou, P. – Guerrero, L. – Arnau, J.: Effect of sodium chloride replacement on some characteristics of fermented sausages. Meat Science, *65*, 2003, pp. 833–839. DOI: 10.1016/S0309-1740(02)00288-7.
17. Gimeno, O. – Astiasaran, I. – Bello, J.: A mixture of potassium, magnesium, and calcium chlorides as a partial replacement of sodium chloride in dry fermented sausages. Journal of Agricultural and Food Chemistry, *46*, 1998, pp. 4372–4375. DOI: 10.1021/jf980198v.
18. Gimeno, O. – Astiasaran, I. – Bello, J.: Influence of partial replacement of NaCl with KCl and $CaCl_2$ on microbiological evolution of dry fermented sausages. Food Microbiology, *18*, 2001, pp. 329–334. DOI: 10.1006/fmic.2001.0405.
19. Campagnol, P. C. B. – dos Santos, B. A. – Wagner, R. – Terra, N. N. – Pollonio, M. A. R.: The effect of yeast extract addition on quality of fermented sausages at low NaCl content. Meat Science, *87*, 2011, pp. 290–298. DOI: 10.1016/j.meatsci.2010.11.005.
20. Genccelep, H. – Kaban, G. – Kaya, M.: Effects of starter cultures and nitrite levels on formation of biogenic amines in sucuk. Meat Science, *77*, 2007, pp. 424–430. DOI: 10.1016/j.meatsci.2007.04.018.
21. Zanardi, E. – Ghidini, S. – Conter, M. – Lanieri, A.: Mineral composition of Italian salami and effect of NaCl partial replacement on compositional, physico-chemical and sensory parameters. Meat Science, *86*, 2010, pp. 742–747. DOI: 10.1016/j.meatsci.2010.06.015.
22. Campagnol, P. C. B. – dos Santos, B. A. – Morgano, M. A. – Terra, N. N. – Pollonio, M. A. R.:

Application of lysine, taurine, disodium inosinate and disodium guanylate in fermented cooked sausages with 50% replacement of NaCl by KCl. Meat Science, *87*, 2011, pp. 239–243. DOI: 10.1016/j.meatsci.2010.10.018.

23. Ibanez, C. – Quintanilla, L. – Cid, C. – Astiasaran, I. – Bello, J.: Dry fermented sausages elaborated with *Lactobacillus plantarum-Staphylococcus carnosus*. Part I: Effect of partial replacement of NaCl with KCl on the stability and the nitrosation process. Meat Science, *44*, 1996, pp. 227–234. DOI: 10.1016/S0309-1740(96)00035-6.
24. Dos Santos, B. A. – Campagnol, P. C. B. – Morgano, M. A. – Pollonio, M. A. R.: Monosodium glutamate, disodium inosinate, disodium guanylate, lysine and taurine improve the sensory quality of fermented cooked sausages with 50% and 75% replacement of NaCl with KCl. Meat Science, *96*, 2014, pp. 509–513. DOI: 10.1016/j.meatsci.2013.08.024.
25. Gimeno, O. – Astiasaran, I. – Bello, J.: Calcium ascorbate as a potential partial substitute for NaCl in dry fermented sausages: Effect on colour, texture and hygienic quality at different concentrations. Meat Science, *57*, 2001, pp. 23–29. DOI: 10.1016/S0309-1740(00)00070-X.
26. Ordonez, J. A. – Hierro, E. M. – Bruno, J. M. – de la Hoz, L.: Changes in the components of dry-fermented sausages during ripening. Critical Reviews in Food Science and Nutrition, *39*, 1999, pp. 329–367. DOI: 10.1080/10408699991279204.
27. Gan, X. – Zhao, L. – Li, J. – Tu, J. – Wang, Z.: Effects of partial replacement of NaCl with KCl on bacterial communities and physicochemical characteristics of typical Chinese bacon. Food Microbiology, *93*, 2021, article 103605. DOI: 10.1016/j.fm.2020.103605.
28. Gimeno, O. – Astiasaran, I. – Bello, J.: Influence of partial replacement of NaCl with KCl and $CaCl_2$ on texture and color of dry fermented sausages. Journal of Agricultural of Food and Chemistry, *47*, 1999, pp. 873–877. DOI: 10.1021/jf980597q.
29. Dos Santos, B. A. – Campagnol, P. C. B. – da Cruz, A. G. – Morgano, M. A. – Wagner, R. – Pollonio, M. A. R.: Is there a potential consumer market for low-sodium fermented sausages? Journal of Food Science, *80*, 2015, pp. S1093–S1099. DOI: 10.1111/1750-3841.12847.
30. Teixeira, A. – Dominguez, R. – Ferreira, I. – Estevinho, L. – Rodriguez, S. – Lorenzo, J. M.: Effect of NaCl replacement by other salts on the quality of Bisaro pork sausages (PGI Chouriça de Vinhais). Foods, *10*, 2021, article 961. DOI: 10.3390/foods10050961.
31. Ercoskun, H. – Tagi, S. – Ertas, A. H.: The effect of different fermentation intervals on the quality characteristics of heat-treated and traditional sucuks. Meat Science, *85*, 2010, pp. 174–181. DOI: 10.1016/j.meatsci.2009.12.022.
32. Hammad, H. H. M. – Meihu, M. – Guofeng, J. – Lichao, H.: Nitroso-hemoglobin preparation and meat product colorant development. Journal of Food Processing and Technology, *8*, 2017, article 1000658. DOI: 10.4172/2157-7110.1000658.
33. Inguglia, E. S. – Zhang, Z. – Tiwari, B. K. – Kerry, J. P. – Burgess, C. M.: Salt reduction strategies in processed meat products: A review. Trends in Food Science and Technology, *59*, 2017, pp. 70–78. DOI: 10.1016/j.tifs.2016.10.016.
34. Armenteros, M. – Aristoy, M. C. – Barat, J. M. – Toldra, F.: Biochemical changes in dry-cured loins salted with partial replacements of NaCl by KCl. Food Chemistry, *117*, 2009, pp. 627–633. DOI: 10.1016/j.foodchem.2009.04.056.

Received 20 October 2021; 1st revised 3 December 2021; accepted 13 December 2021; published online 15 February 2022.