Influence of tallow replacement by oat β-glucan and canola oil on the fatty acid and volatile compound profiles of low-fat beef burgers

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ABSTRACT

In view of the growing expectations of meat products consumers (quality and sensory properties), the meat industry must develop functional products to meet the consumer requirements. In the experiment, the influence of oat β-glucan, canola oil and both on the proximate composition, fatty acid profile, volatile compounds profile and sensory properties of beef burgers was analyzed. The beef tallow replacement by β-glucan, canola oil or both decreased the SFA and increased PUFA content. The consumption of one portion of product with canola oil and β-glucan can provide 57.6% of the daily amount of linolenic acid (C18:3n3). Volatile compounds analysis of grilled samples showed the presence of 1-penten-3-one and 2-methylpropanal only in case of groups with canola oil and butane-2-one in β-glucan group. This strategy improves not only the nutritional value but also the sensory properties and consumer acceptance. The obtained product may be labelled with health claims regarding oat β-glucan.

Influencia del remplazo de sebo por el β-glucano de avena y el aceite de canola en los perfiles de ácidos grasos y compuestos volátiles de hamburguesas de carne de res baja en grasa

RESUMEN

En vista de las crecientes expectativas de los consumidores de productos cárnicos en cuanto a calidad y propiedades sensoriales, la industria cárnica debe desarrollar productos funcionales que cumplan con los requisitos del consumidor. El presente estudio analizó la influencia del β-glucano de avena, el aceite de canola y ambos en la composición pronta, el perfil de ácidos grasos, el perfil de compuestos volátiles y las propiedades sensoriales de las hamburguesas de carne de res. Al remplazar sebo de res por β-glucano, aceite de canola o ambos disminuyó el SFA y aumentó el contenido de PUFA. El consumo de una porción de producto con aceite de canola y β-glucano puede proporcionar 57,6% de la cantidad diaria recomendada de ácido linolénico (C18:3n3). El análisis de compuestos volátiles en muestras a la parrilla indicó la presencia de 1-penteno-3-ona y 2-metilpropanal solo en el caso de grupos que contenían aceite de canola y butano-2-ona en el grupo de β-glucano. Esta estrategia de cambio mejora no solo el valor nutricional sino también las propiedades sensoriales y la aceptación del producto por parte del consumidor. La etiqueta del producto puede indicar las propiedades saludables del β-glucano de avena.

1. Introduction

Beef burgers are one of the most common fast food products in many developed countries in Europe, America and East Asia (Market Research Engine, 2018; Nathwani, 2017). Unfortunately, despite the increasing number of studies proving the lack of influence of SFA cardiovascular disease, present meat fat phobia, (especially fear of saturated or “solid” animal fats), nutritional value of beef fat is questioned by some public health authorities (Frank, Oytam, & Hughes, 2017; Siri-Tarino, Sun, Hu, & Krauss, 2010). Previous generations of consumers, among others in East and Southeast Asia, were choosing fat pieces of meat because of their better sensory features. Today, also some consumers appreciate the unique sensory characteristics of marbled beef. Health authorities, especially of the English-speaking countries, persuaded people that consumption of animal fat, including SFA and solid fats, should be reduced to maintain a healthy nutrition. Years of negative information about animal fats led to a general avoidance of fatty meat (Frank, Joo, & Warner, 2016). Twenty-first-century consumers pay significant attention to the quality of food products, including their fatty acid profile, which has an impact on their health (McManus, Merga, & Newton, 2011). Simultaneously, they are looking for products with attractive sensory features (Hathwar, Rai, Modi, & Narayan, 2012). Therefore, the meat industry must develop functional products to meet the consumer requirements (de Oliveira Fagundes et al., 2017; Marcinkowska-Lesiak, Polawska, Pöttorak, & Wierzbicka, 2017; Munekata et al., 2017; Pöttorak et al., 2018). There are several methods to modify the fatty acid profile of meat products (Osypina-E, Sierra-C, Ochoa, Pérez-Álvarez, & Fernández-López, 2012; Polawska et al., 2013). The fatty acid profile, cholesterol content and precursors of vitamins A and E in beef are mainly determined by marbling (amount of intramuscular fat – IMF) which depends on among others the animal breed and the method of animal feeding (Daley, Abbott, Doyle, Nader, & Larson, 2010; Troy, Tiwari, & Joo, 2013).
As part of the research was to develop a recipe acceptable to consumers low-fat meat product, with sensory properties similar to the control sample, which would be composed of \( \beta \)-glucan by at least 1%. The resulting product should be able to adhere to the following health claims: ‘\( \beta \)-glucans contribute to the maintenance of normal blood cholesterol levels’ and ‘the consumption of \( \beta \)-glucans from oats or barley as part of a meal contributes to the reduction of blood glucose rise after a meal’ (Commission Regulation (EU) No 432/2012, n.d).

2. Materials and methods

2.1. Treatments and beef burgers preparation

Beef chucks (source: Meat Plant Wierzejki Ltd, Poland) peeled on the outside from subcutaneous fat and connective tissue were chopped and minced in a meat grinder using a \( \Omega \) 8 mm plate (PI-TU-T, Edesa, Spain). Samples were prepared for four different formulations: Control; O – substitution of 40% beef tallow with canola oil; B – beef tallow replacement by 30% oat \( \beta \)-glucan concentrate (4% of product); O + B – substitution of 40% beef tallow with canola oil and total fat replacement by 30% oat \( \beta \)-glucan concentrate (4% of product). The composition of control and low-fat burgers with added \( \beta \)-glucan concentrates and canola oil is presented in Table 1. Thirty percent \( \beta \)-glucan concentrate extracted without chemicals, using the hydrothermal extraction method, from the oat grain Avena Sativa aleuronic layer (Microstructure Inc., Poland) containing: 20.36% proteins, 10.69% carbohydrates, 8.65% fat and 64.12% fibre (34.10% insoluble fractions and 30.03% soluble fractions, including 30 g of \( \beta \)-glucan per 100 g) was used. All ingredients were mixed and 150 g burgers (2.1 cm thickness) were formed using an aluminium forming press (10 cm in diameter).

Products were heat treated in standardised conditions by electrical grill (Silex S-Tronic Single Grill S161GR, Germany), and pre-heated using top (210°C) and bottom (190°C) heating plates. Samples were heat treated for 180 s to reach 75°C at their geometric centre (TrackSense® Pro, Ellab, Denmark).

2.2. Proximate composition

Raw samples’ basic composition (moisture, protein, fat ash and connective tissue content) was determined using a near-infrared

| Component (%) | Control | O | B | O + B |
|---------------|---------|---|---|-------|
| Beef chuck    | 77.3    | 77.3 | 77.3 | 77.3 |
| Water         | 1.9     | 1.9 | 1.9 | 1.9 |
| Black pepper  | 0.4     | 0.4 | 0.4 | 0.4 |
| Salt          | 1.1     | 1.1 | 1.1 | 1.1 |
| Beef tallow   | 19.3    | 11.6 | 15.3 | 9.6 |
| Canola oil    | 0.0     | 7.0 | 0.0 | 5.7 |
| Oat \( \beta \)-glucan concentrate 30% | 0.0 | 0.0 | 4.0 | 4.0 |

Table 1. Proportion of ingredients used in prepared beef burgers with canola oil and fat replacement levels by 30% oat \( \beta \)-glucan concentrate. Treatments: Control; O – substitution of 40% beef tallow with canola oil; B – beef tallow replacement by 30% oat \( \beta \)-glucan concentrate (4% of product); O + B – substitution of 40% beef tallow with canola oil and total fat replacement by 30% oat \( \beta \)-glucan concentrate (4% of product).

Table 1. Proportion of ingredients used in the hamburguesas de carne de res preparadas con aceite de canola y niveles de remplazo de grasa por 30% de concentrado de \( \beta \)-glucano de avena. Tratamientos: Control; O – sustitución de 40% de sebo de res con aceite de canola; B – remplazo de 30% de sebo de res por el concentrado de \( \beta \)-glucano de avena (4% del producto); O + B – sustitución de 40% de sebo de res con aceite de canola y remplazo total de grasa por 30% de concentrado de \( \beta \)-glucano de avena (4% del producto).
spectrometer NIRFlex N-500 Büchi contained in a NIRFlex Solids module (Büchi Labortechnik AG, Switzerland) in the spectral range of 12,500–4,000 cm⁻¹ in reflectance mode, and the application of Büchi Art. N. N555-501. Evaluation of basic composition was carried out in a near-infrared laboratory accredited by the Polish Centre for Accreditation FT-NIR (Accreditation No. AB 1670), according to the method described by Wyrwisz, Półtorak, Zalewska, Zaremba, and Wierzbicka (2012). One hundred grams of homogenised meat product was placed on a Petri dish and measured six times at a 32 scanning rate for each sample.

2.3. Fatty acid profile evaluation

Fatty acids were extracted from the raw and grilled samples with chloroform–methanol, according to the procedure by Folch, Lees, and Sloane (1956). The fatty acid methyl esters (FAMES) were formed according to method presented by Ichihara and Fukubayashi (2010) using a KOH solution in methanol. FAMES were extracted using water and hexane. The hexane layer (containing FAME) was dehydrated through anhydrous Na₂SO₄. For analysis extracted and dehydrated hexane was transferred to a vials. FAMES were analysed using a Shimadzu GC-2010 gas chromatograph with a flame ionisation detector (FID) and equipped with an RT™ 2560 silica column (100 m × 0.25 mm ID and 0.2 µm film thickness) (RESTEK, USA). Chromatographic conditions were as follows: initial oven temperature of 140°C (held for 5 min), ramp at 48°C/min to 240°C and then held for 30 min. Injector and detector temperatures were 240°C and 260°C, respectively. Split ratio was 80:1 and the volume of injection was 1 µl. The carrier gas was helium with a flow rate of 1.0 ml/ min. Each sample was measured in triplicate. FAMES were identified by comparison of their retention times with those of the reference standards (Supelco™ 37 Component FAME mix, Sigma, St Louis, MO, USA). The results were expressed in grams per 100 g of fat of detected FAMES.

2.4. Volatile compound profile evaluation

The profile of volatile compound was analysed in raw and grilled samples using Electronic Nose Heracles II (Alpha M.O. S., Toulouse, France). Analysis was based on ultrafast gas chromatography with headspace (HS-GC) according to the method described in work Wojtasik-Kalinowska et al. (2016). The device is included: an automatic sampling system and system of detection containing non-polar MXT-5 column and slightly polar MXT-1701 (length: 10 m, diameter: 180 mm) connected to a FID. The device was operated using AlphaSoft software (Alpha Software Corporation, Massachusetts, USA). The burger samples (3 g) were placed in 20 ml headspace vials. The samples were capped with a Teflon-faced silicon rubber cap and placed in the automatic sampler of the headspace system. Each sample was incubated at 55°C for 15 min under 8.33 Hz agitation. Hydrogen (the carried gas) was circulated at 1 mL min⁻¹. The accumulated gas was injected by autosampler from the headspace into GC (injection speed 125 ml s⁻¹). The injected volume was 3500 ml and the injector temperature was 200°C. The analytes were accumulated in a trap at 15°C (Tenax). The temperature program included: 60°C for 2 s; 3°C Cs⁻¹ ramp to 270°C and kept for 20 s. The FID was 280°C. The method was calibrated by an alkane solution [n-butane to n-hex-adiacene (Restek)] in order to convert retention time into Kovats Indices (Goodner, 2008). The profile of volatile compound was evaluated in six repetitions in three independent biological replicates. Volatile compounds were recognised using the AroChemBase library. The library contains 44 000 compounds and includes also a base of sensory descriptors for each single compound. In this study, the C11 peak was chosen as the reference peak to be monitored in time by the software.

2.5. Sensory evaluation

Sensory evaluation of the grilled products was performed by 120 untrained panellists recruited among students (19–24 years old) of the Warsaw University of Life Sciences (WULS) according to modified Meat Standards Australia (MSA, 2008) method. Sensory session of burgers were performed at 23 ± 1°C in isolated rooms with white light. In each session attended 20 consumers. Coded burgers (three-digit codes) were served on plastic plates in random order (four samples per consumer + one link sample). Link product was served as a first before four test samples. Position and carryover effects were completely balanced using a 4 × 4 Latin square design to allocate products to consumers. Information about consumer acceptance were recorded according to method described by Szpicer, Onopiuk, Półtorak, and Wierzbicka (2018). For each sample, consumers were asked to indicate their degree of liking on a 100 mm line scale. Consumers placed a vertical line in range samples from 0 mm (‘extremely dislike’) to 100 mm (‘extremely like’). Consumers were asked to evaluate the following descriptors: external appearance, colour, aroma, taste, juiciness, texture, overall acceptability. Variance due to panellists and sessions was considered for the sensory data.

2.6. Statistical analysis

The statistical analysis of the obtained results was carried out with Statistica 13.3 (StatSoft Inc., Tulsa, USA). Production and measurements were taken for each of three independent biological replicates, where different ingredients were used. The results are presented as the mean. The effects of the treatment group were analysed using the general linear model (GLM) procedure with Tukey’s test at a level of significance of α = 0.05.

3. Results and discussion

3.1. Proximate composition

The proximate composition (content of moisture, fat, protein, ash and connective tissue) of samples from different treatments is presented in Table 2. The oat β-glucan water-binding capacity was the reason of increase moisture value. Consequently, the moisture level of all samples with β-glucan addition (B and O + B samples) caused a significant increase of the moisture level (P < 0.05) (Ahmad, Muhammad, Zahoor, Nawaz, & Ahmed, 2010). Also, protein and ash value increased after addition of β-glucan and β-glucan with canola oil (B and O + B groups) (P < 0.05). Significant decrease of fat level was observed in samples oat β-glucan concentrate (B and O + B) (P < 0.05). The recipe modifications did not cause significant changes in connective tissue level (P > 0.05).
### 3.2. Fatty acid profile evaluation

The beef tallow and canola oil fatty acid profiles were analysed. Results of fatty acid profile analysis of raw material used in experiment (Table 3) are in line with expectations and are confirmed with reports presented by Daley et al. (2010) and Orsavova, Misurcova, Ambrozova, and Vicha (2015). The most abundant fatty acids in both samples was C18:1n9c, respectively, 33.66 g/100 g – beef tallow and 65.02 g/100 g – canola oil. Unfortunately, beef tallow was also characterized by a high content of C16:0 31.73 g/100 g in contrast to canola oil, which contained a high content of PUFA like C18:2n6c and C18:3n3c (respectively, 18.57 g/100g and 7.57 g/100g) (Daley et al., 2010; Orsavova et al., 2015).

Comparison of fatty acid profiles showed that the canola oil has over 9 times lower total SFA content than beef tallow. This is one of the most important factors confirming the high quality of canola oil and its nutritional value (Bree, De, Laitinen, & Flötter, 2009).

The fatty acid profile of raw (Table 4) and grilled (Table 5) burgers is presented in Tables 4 and 5 respectively. In quantitative terms, palmitic acid (C16:0) and stearic acid (C18:0) were the major SFAs detected in raw and grilled burgers in all analysed groups. The most abundant MUFA was oleic acid (C18:1n9c). The beef tallow replacement by β-glucan (B group), canola oil (O group) or both (O + B group) decreased significantly the SFA content and increased PUFA level (P < 0.05). These observations are in agreement with data presented by Haghshenas et al. (2015), who evaluated the influence of carboxymethyl cellulose and β-glucan in shrimp nuggets and Belichovska, Pejkovski, Belichovska, Uzunoska, and Silovska-Nikolova (2017), who analysed the influence of vegetable oil content in chicken frankfurters, and noticed a decrease in SFA levels in meat products with fat replaced by β-glucan and canola oil. Linoleic acid (C18:2n6c) was the main PUFA found in raw and grilled products. As canola oil has a high content of linoleic acid (C18:3n3) (Table 3), a significant increase of this fatty acid was obtained in O and O + B groups (P < 0.05). As a result, the consumption of one portion (150 g) of grilled product can provide 67.8% (O group) and 57.6% (O + B group) of the daily amount of linoleic acid (C18:3n3) recommended by the consumption of one portion (150 g) of grilled product can provide 67.8% (O group) and 57.6% (O + B group) of the daily amount of linoleic acid (C18:3n3) recommended by...
Table 4. Effect of the partial replacement of beef tallow by canola oil; oat β-glucan concentrate or both of them on fatty acids profile (expressed as g/100 g of fatty acids) of raw beef burger.

|       |       |       |       |       |
|-------|-------|-------|-------|-------|
|       | Control | O     | O + B | SEM   |
| C10:0 | 0.03   | 0.02  | 0.03  | 0.02  | 0.001 |
| C12:0 | 0.03   | 0.02  | 0.03  | 0.02  | 0.001 |
| C14:0 | 2.74   | 1.69  | 2.68  | 1.34  | 0.103 |
| C14:1n5c | 0.26 | 0.22  | 0.24  | 0.16  | 0.007 |
| C15:0 | 0.27   | 0.18  | 0.25  | 0.15  | 0.008 |
| C16:0 | 20.57  | 29.73 | 17.50 | 9.936 |
| C16:1n7c | 2.80  | 2.17  | 2.68  | 1.75  | 0.073 |
| C17:0 | 0.93   | 0.59  | 0.86  | 0.48  | 0.031 |
| C17:1n7c | 0.42  | 0.36  | 0.38  | 0.30  | 0.007 |
| C18:0 | 22.65  | 13.62 | 21.71 | 11.47 | 0.826 |
| C18:1n9c | 1.09  | 0.70  | 1.02  | 0.58  | 0.036 |
| C18:1n9c | 36.01 | 47.87 | 36.37 | 50.16 | 1.093 |
| C18:2n6c | 0.23  | 0.11  | 0.20  | 0.09  | 0.010 |
| C18:2n6c | 1.35  | 7.49  | 2.49  | 10.42 | 0.624 |
| C18:3n3c | 0.39  | 2.86  | 0.45  | 3.64  | 0.244 |
| C18:3n6c | ND    | ND    | ND    | 0.09  | 0.007 |
| C20:0 | 0.17   | 0.26  | 0.18  | 0.30  | 0.009 |
| C20:1c | 0.22  | 0.62  | 0.25  | 0.75  | 0.036 |
| C20:2c | 0.02   | 0.02  | 0.02  | 0.03  | 0.001 |
| C20:3n6c | 0.05  | 0.04  | 0.04  | 0.05  | 0.001 |
| C20:4n6c | 0.04  | 0.04  | 0.04  | 0.04  | 0.001 |
| C21:0 | 0.02   | 0.00  | 0.02  | 0.01  | 0.002 |
| C22:0 | 0.04   | 0.13  | 0.05  | 0.15  | 0.008 |
| C22:1n9c | ND   | 0.07  | ND    | 0.09  | 0.007 |
| C22:2n6c | 0.02  | 0.01  | 0.02  | 0.02  | 0.003 |
| C24:0 | 0.01   | 0.04  | 0.03  | 0.03  | 0.003 |
| C24:1n9c | ND   | 0.04  | ND    | 0.05  | 0.003 |
| ΣSFA | 57.09  | 37.40 | 55.77 | 31.52 | 1.892 |
| ΣMUFA | 40.86  | 52.04 | 40.76 | 53.85 | 1.031 |
| ΣPUFA | 2.09   | 10.69 | 3.26  | 14.69 | 0.882 |
| PUFA/SFA | 0.04  | 0.29  | 0.06  | 0.43  | 0.030 |
| AI | 0.95    | 0.42  | 0.92  | 0.33  | 0.048 |
| Tl | 2.32    | 0.88  | 2.20  | 0.65  | 0.127 |
| h/H | 1.20    | 2.61  | 1.25  | 3.47  | 0.162 |
| LA/LNA | 3.49  | 2.62  | 5.49  | 2.83  | 0.191 |
| n6/n3 | 4.21   | 2.69  | 5.96  | 2.72  | 0.227 |

SEM: standard error of the mean;
SFA = satu rating fatty acids;
MUFA = monounsaturated fatty acids;
PUFA = polyunsaturated fatty acids;
n = 6 = omega-6; n = 6 = omega-3
AI: atherogenic index;
TI: thrombogenic index;
IA: index of atherogenicity = (12:0 + 4 × 14:0 + 16:0)/(MUFA + PUFA) calculated according to Ulbricht & Southgate (1991);
IT: index of thrombogenicity = (12:0 + 16:0 + 18:0)/(0.5 × MUFA + 0.5 × n-6 PUFA) + (3 × n-3 PUFA)/[(n-3 PUFA/n-6 PUFA) + (n-3 PUFA/n-6 PUFA)] calculated according to Ulbricht & Southgate (1991);
h/H: hypocholesterolemic/hypercholesterolemic ratio [(C18:1 + PUFA)/[(C14:0 + 16:0)] calculated according to Manuela Fernández (2007);
LA/LNA: linoleic/o-linolenic acid ratio
n6/n3: omega-6/omega-3 ratio
ND: not detected.
(a, b, c, d) – means with different letters in show significant effect of treatment group P ≤ 0.05
SEM: error estándar de la media;
SFA = ácidos grasos saturados;
MUFA = ácidos grasos monounsaturados;
PUFA = ácidos grasos poliinsaturados;
n = 6 = omega-6; n = 6 = omega-3
AI: índice aterogénico;
TI: índice trombogénico;
IA: índice de aterogenidad = (12:0 + 4 × 14:0 + 16:0)/(MUFA + PUFA) calculado según Ulbricht y Southgate (1991);
IT: índice de trombogénidad = (12:0 + 16:0 + 18:0)/(0.5 × MUFA) + 0.5 × n-6 PUFA) + (3 × n-3 PUFA)/[(n-3 PUFA/n-6 PUFA)] calculado de acuerdo con Ulbricht y Southgate (1991);
h/H: relación hipocolesterolemica/hipercolesterolemica [(C18:1 + PUFA)/[(C14:0 + 16:0)] calculada según Manuela Fernández (2007);
LA/LNA: relación de ácido linoleico/o-linolénico
n6/n3: relación omega-6/omega-3
ND: no detectado.
(a, b, c, d) – significa con letras diferentes en mostrar un efecto significativo del grupo de tratamiento P ≤ 0.05
The substitution of beef tallow by canola oil (O and O + B) samples compared to the recommended value (between 1:1 and 2:1) (Simopoulos, 2011). Modification of the recipe had a tendency of n6/n3 ratio significant changes was observed in canola oil. Analysis showed higher n6/n3 ratio in raw control samples compared to the recommended value (between 1:1 and 2:1) (Simopoulos, 2011). Modification of the recipe had a significant effect on the n6/n3 ratio in raw and gilled samples. The substitution of beef tallow with canola oil (O and O + B) samples significantly lowered the n6/n3 ratio in relation to the control samples ($P < 0.05$). In contrast to the samples with canola oil, the raw burgers with β-glucano (B) were characterized by a significantly higher n6/n3 ratio ($P < 0.05$). The same tendency of n6/n3 ratio significant changes was observed in

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|     | Control | O       | B       | O + B   | SEM     |
|-----|---------|---------|---------|---------|---------|
| C18:0 | 0.03d   | 0.02b   | 0.02b   | 0.00b   | 0.002   |
| C18:1 | 0.03d   | 0.02b   | 0.01a   | 0.02b   | 0.001   |
| C18:2 | 2.57b   | 1.83b   | 2.15b   | 1.96b   | 0.068   |
| C18:3 | 0.01c   | 0.28c   | 0.37b   | 0.29b   | 0.007   |
| C18:4 | 23.24d  | 15.01a  | 22.48b  | 15.97b  | 0.629   |
| C18:5 | 1.09d   | 0.68a   | 1.05a   | 0.73b   | 0.030   |
| C18:6 | 34.83a  | 46.63a  | 35.58b  | 44.50b  | 0.829   |
| C18:7 | 0.23c   | 0.12a   | 0.20a   | 0.14b   | 0.006   |
| C18:8 | 0.01c   | 0.70f   | 0.34d   | 0.24a   | 0.197   |
| C18:9 | 0.29a   | 0.07d   | 0.06d   | 0.06b   | 0.006   |
| C20:0 | 0.19b   | 0.30d   | 0.17a   | 0.28a   | 0.009   |
| C20:1 | 0.22a   | 0.64a   | 0.23a   | 0.55b   | 0.032   |
| C20:2 | 0.01a   | 0.02e   | 0.01c   | 0.02a   | 0.002   |
| C20:3 | 0.02c   | 0.02e   | 0.03b   | 0.03b   | 0.001   |
| C20:4 | 0.02c   | 0.01f   | 0.00b   | 0.01c   | 0.002   |
| C21:0| 0.02a   | 0.05c   | 0.01b   | 0.01c   | 0.003   |
| C22:0| 0.04b   | 0.13d   | 0.03c   | 0.12c   | 0.008   |
| C22:1| ND      | 0.08    | ND      | 0.06    | 0.006   |
| C22:2| ND      | 0.01c   | 0.06b   | 0.01b   | 0.005   |
| C24:0| ND      | 0.05c   | 0.01b   | 0.04c   | 0.003   |
| C24:1| ND      | 0.04    | ND      | 0.04    | 0.003   |
| ΣSFA | 58.03d  | 39.77a  | 57.47a  | 41.62b  | 1.493   |
| ΣMUFA| 39.57a  | 49.73a  | 40.02a  | 48.11b  | 0.781   |
| ΣPUFA| 15.5a   | 10.48a  | 2.43a   | 9.56a   | 0.684   |
| PUFA/SFA | 0.03a | 0.26f | 0.04a | 0.23b | 0.018 |
| AI  | 1.04d   | 0.47e   | 0.98a   | 0.52b   | 0.044   |
| TI  | 2.54d   | 0.96e   | 2.39d   | 1.09b   | 0.122   |
| h/H | 1.10b   | 2.51d   | 1.79b   | 2.27c   | 0.107   |
| LA/LNA | 3.25b | 2.62c | 5.47c | 2.85c | 0.194 |
| n6/n3 | 4.12b | 2.70a | 6.28e | 2.95e | 0.241 |

SEM: standard error of the mean;
SFA = saturated fatty acids;
MUFA = monounsaturated fatty acids;
PUFA = polyunsaturated fatty acids;
n = 6 = omega-6; n = 3 = omega-3
AI: atherogenic index;
TI: thrombogenic index;
IA: index of atherogenicity = (12:0 + 4 × 14:0 + 16:0)/(MUFA + PUFA) calculated according to Ulbricht & Southgate (1991);
IT: index of thrombogenicity = (12:0 + 16:0 + 18:0)/(0.5 × MUFA + 0.5 × n-6 PUFA + 3 × n-3 PUFA + (n-3 PUFA/n-6 PUFA)) calculated according to Ulbricht & Southgate (1991);
h/H: hypcholesterolemic/hypercholesterolemic ratio [(C18:1+ PUFA)/(C14:0 + 16:0)] calculated according to Manuela Fernández (2007);
LA/LNA: linoleic/o-linoleinic acid ratio
n6/n3: omega-6/omega-3 ratio
ND: not detected.
(a, b, c, d) – means with different letters in show significant effect of treatment group $P < 0.05$
SEM: error estándar de la media;
SFA = ácidos grasos saturados;
MUFA = ácidos grasos monoisaturados;
PUFA = ácidos grasos poliinsaturados;
n = 6 = omega-6; n = 3 = omega-3
AI: índice aterogénico;
TI: índice trombogénico;
IA: índice de aterogenicidad = (12:0 + 4 × 14:0 + 16:0)/(MUFA + PUFA) calculado según Ulbricht y Southgate (1991);
IT: índice de trombogénico = (12:0 + 16:0 + 18:0)/(0.5 × MUFA + 0.5 × n-6 PUFA + 3 × n-3 PUFA + (n-3 PUFA/n-6 PUFA)) calculado de acuerdo con Ulbricht y Southgate (1991);
h/H: relación hipcholesterolemica/hypercholesterolemica [(C18:1 + PUFA)/(C14:0 + 16:0)] calculada según Manuela Fernández (2007);
LA/LNA: relación de ácido linoleico/o-linolénico
n6/n3: relación omega-6/omega-3
ND: no detectado.
(a, b, c, d) – significa con letras diferentes en mostrar un efecto significativo del grupo de tratamiento $P < 0.05$
grilled samples (P < 0.05). On the other hand, Afshari, Hosseini, Khaneghah, and Khakzar (2017) showed the decrease of n6/n3 ratio in burgers formulated with total beef fat replacement by canola oil and olive oil with soy protein isolate containing inulin and β-glucan. Thermal treatment of the samples resulted in an increase of SFA content in all analyzed samples. The highest increase (about 10 g/100 g) was recorded for the O + B sample. A decrease in MUFA content caused by grilling was observed in all analysed samples; however, the highest changes were observed in samples O and O + B. Similar changes caused by grilling were observed for PUFA content. Despite the changes caused by thermal treatment, O and O + B burgers were characterized by the highest PUFA/SFA ratio among the remaining samples. Obtained products will ensure adequate supply of linoleic acid (C18:2n6) and alpha-linolenic acid (C18:3n3) in diet – sufficient intake (AI) set at 4% and 0.5%, respectively, of the energy value of the diet (EFSA, 2011), and help in the implementation of the ‘Twelve steps to healthy eating’ recommended by the World Health Organization (replacing the majority of saturated fats by unsaturated fats) (WHO, 2000).

### 3.3. Volatile compound evaluation

Tables 6 and 7 show the 26 characteristic volatile compounds identified in all analysed groups of raw and grilled samples, respectively. In the case of raw burgers, 12 compounds were identified in the control group, 13 in O group, 14 in B group and 12 in O + B group. In the case of grilled meat, there were 18 compounds in the control group, O and O + B groups, and 17 in the B group. Raw meat is characterized by a very weak odour; however, it constitutes a matrix rich in non-volatile precursors of volatile compounds responsible for the development of meat products flavor (Kosowska, Majcher, & Fortuna, 2017). Free amino acids, particularly the sulfuric ones like cysteine and methionine, are the basic substrates in Maillard reactions and Strecker’s degradation reaction (Whitfield, 2009). The Strecker degradation of amino acids is one of the main reactions leading to the final aroma compounds in the Maillard reaction (Villaverde, Ventanas, & Estévez, 2014). Only in the case of grilled beef the formation of Strecker’s aldehydes (3-methyl-butanal) has been observed. Among other reported

#### Table 6. Volatile compounds recognized by AroChemBase in raw burger samples (relative area of peaks [%]).

| Group/compound | K MXT-5 | K MXT-17 | Control | O | B | O + B | SEM |
|----------------|---------|----------|---------|---|---|------|-----|
| Aldehyde       |         |          |         |   |   |      |     |
| propanal       | 451     | 579      | Ethereal| 27.13<sup>a</sup> | 39.04<sup>b</sup> | 41.1<sup>c</sup> | 38.22<sup>b</sup> | 0.680 |
| 2-methylpentanal| 515     | 837      | Earthy  | 12.6<sup>a</sup> | 15.51<sup>b</sup> | ND  | ND  | 0.267 |
| 2-methylpropanal| 516     | 626      | Burnt   | ND  | ND  | 13.54<sup>a</sup> | 16.63<sup>b</sup> | 0.904 |
| 3-methylbutanl  | 665     | 729      | Almond  | ND  | ND  | ND  | ND  | 0.025 |
| 2-methylbutanl  | 734     | 794      | Almond  | ND  | ND  | 0.43  | ND  | 0.024 |
| benzeneacetaldheyde| 1025    | 1199     | Floral  | 0.82<sup>a</sup> | 0.78<sup>b</sup> | 1.13<sup>b</sup> | 0.72<sup>c</sup> | 0.024 |
| (E, E)-2,4-nonadienal| 1208    | 1287     | Fatty   | 0.74<sup>a</sup> | 0.91<sup>b</sup> | 0.98<sup>c</sup> | ND  | 0.018 |
| Alcohol        |         |          |         |   |   |      |     |
| ethanol        | 422     | 563      | Alcoholic| 0.22<sup>a</sup> | 0.92<sup>b</sup> | 4.28<sup>c</sup> | 0.64<sup>c</sup> | 0.195 |
| 2-methyl-2-propanol| 480     | 627      | ND      | ND  | ND  | ND  | ND  | 0.025 |
| 1-Propanol     | 551     | 661      | Alcoholic| 2.52<sup>a</sup> | 2.31<sup>b</sup> | 7.89<sup>c</sup> | 7.93<sup>c</sup> | 0.330 |
| 2-furanmethanol| 850     | 1023     | Bread   | ND  | ND  | ND  | ND  | 0.025 |
| Ketone         |         |          |         |   |   |      |     |
| butane-2,3-dione| 567     | 683      | Butter  | 1.21<sup>a</sup> | 2.31<sup>b</sup> | 2.17<sup>b</sup> | 4.02<sup>c</sup> | 0.124 |
| butane-2-one   | 589     | 696      | Butter  | ND  | ND  | 0.71  | ND  | 0.025 |
| 1-penten-3-one | 676     | 787      | Fishy   | ND  | ND  | ND  | ND  | 0.025 |
| Alkane         |         |          |         |   |   |      |     |
| octane         | 790     | 800      | Alcane  | ND  | ND  | ND  | 0.40 | 0.009 |
| nonanone       | 883     | 900      | Alkane  | 5.90<sup>a</sup> | 3.63<sup>b</sup> | 2.65<sup>c</sup> | 3.68<sup>c</sup> | 0.153 |
| Amine          |         |          |         |   |   |      |     |
| 1-butanamine   | 629     | 702      | Ammoniacal| ND  | ND  | ND  | ND  | 0.028 |
| Ester          |         |          |         |   |   |      |     |
| methyl isobutryate| 677     | 739      | Floral  | ND  | 0.63 | ND  | ND  | 0.028 |
| methyl butanoate| 713     | 788      | Ester   | ND  | ND  | ND  | ND  | 0.028 |
| ethyl isobutyrate| 763     | 813      | Fruity  | 1.34<sup>a</sup> | 1.99<sup>b</sup> | 2.29<sup>b</sup> | 2.08<sup>c</sup> | 0.044 |
| Sulfur compounds |         |          |         |   |   |      |     |
| dimethyl sulfide| 450     | 559      | Cabbage | ND  | ND  | ND  | ND  | 0.012 |
| dimethyl sulfide| 733     | 778      | Cabbage | ND  | ND  | 0.40  | ND  | 0.012 |
| Pyrazine       |         |          |         |   |   |      |     |
| 2,3-dimethylpyrazine| 901     | 1005     | Bread   | ND  | ND  | ND  | ND  | 0.012 |
| Terpene        |         |          |         |   |   |      |     |
| 1R-(+)-alpha-pinene| 927     | 939      | Pine    | 11.10<sup>a</sup> | 7.32<sup>b</sup> | 7.71<sup>c</sup> | 8.83<sup>b</sup> | 0.190 |
| 1S-(-)-alpha-pinene| 953     | 945      | Herbaceous| 20.62<sup>a</sup> | 14.59<sup>b</sup> | ND  | 13.14<sup>a</sup> | 0.471 |
| beta-pinene    | 969     | 994      | Green   | 15.28<sup>a</sup> | 12.36<sup>b</sup> | 12.06<sup>c</sup> | 11.64<sup>c</sup> | 0.295 |

* MXT-5 – non polar column.
** MXT-1701 – slightly polar column.
ND: not detected.
(a, b, c, d) – means with different letters in show significant effect of treatment group P ≤ 0.05
* MXT-5 – column non polar.
** MXT-1701 – columna ligeramente polar.
ND: no detectado.
(a, b, c, d) – Las medias con letras diferentes muestran un efecto significativo del grupo de tratamiento P ≤ 0.05.
previously in literature compounds derived from Maillard and Strecker reactions are for example; methylpyrazine, 2-ethyl-3,5-dimethyl-pyrazine, trimethylpyrazine, 2-acetyl-1-pyrroline and 2-acetyl-2-thiazoline (Frank et al., 2017). Keton (butane-2,3-dione) was present in all analyzed groups, except grilled sample (B). The compound can be formed from the 2,3-enolization pathway which form part of the Maillard reaction. The presence of these compound in raw meat can be associated with pH value (Legako, Dinh, Miller, Adhikari, & Brooks, 2016). Aldehydes like propanal and hexanal are often used as indicators of the lipid oxidation in foods, because they can be measured in the sample headspace, and their lack of double bonds makes them more oxidatively stable than unsaturated aldehydes. Modification of the recipe also cause an increase in relative area of peaks of (E,E)-2,4-heptadienal in grilled samples. This compound is characterized by a fishy smell. A compound, 1-penten-3-one, is suspected to be responsible for this (Sghaier et al., 2014). In this study, the presence of 1-penten-3-one was observed only in the case of canola oil, the off-flavours formed during heating are characterized by a fishy smell. A compound, 1-penten-3-one, is suspected to be responsible for this (Sghaier et al., 2016). 1-propanol was detected in the control and B groups only in raw burgers, whereas the presence of 2-furanmethanol was noticed in the control group of grilled burgers. 2-furanmethanol is a product of Maillard reactions (Ames, Guy, & Kipping, 2001). The formation of alcohol compounds like 2-furanmethanol is triggered by thermal degradations of fatty acids (Elmore, Campo, Enser, & Mottram, 2012). In the case of canola oil, the off-flavours formed during heating are characterized by a fishy smell. A compound, 1-penten-3-one, is suspected to be responsible for this (Sghaier et al., 2016). In this study, the presence of 1-penten-3-one was observed only in the case of groups where canola oil was added. Jiang et al. (2011) reported that the addition of PUFAs to the minced beef resulted in a decrease in beef flavour and an increase in off-flavour. Dimethyl sulfide and dimethyl disulfide were present in grilled burgers (control, B, O + B groups). Both dimethyl sulfide and dimethyl disulfide were not detected in groups where canola oil was added. It can be assumed that in groups with oil addition, the characteristic meaty flavour was not as intense, which was correlated with the consumers’ evaluation. 2,3 dimethylpyrazine was identified in all grilled burgers. Compounds identified both in raw and grilled meat included: propane,
ethanol, nonane, ethyl isobutyrate, 1R(+)-alpha-Pinene and beta-Pinene. Changes in the volatile compound profile in samples with β-glucan addition are probably caused by the addition of fibres, which by consequence decrease the meaty aroma (Sánchez-Zapata et al., 2010; Troutt et al., 1992). Additionally, the source of flavours in grilled meat products are mainly amino acids and lipids. Substitutes of meat fat also influence the volatile compound profile by altering flavour compounds and/or by reducing the primary flavour-generating source (meat fat) (Brewer, 2012). The most common fat substitutes, including oat fibre, can increase volatile compound generation in pyrazines and sulphur-containing compounds (Wood, 2011) and some, like maltodextrins and tapioca, can decrease their release (among others they inhibit the release of Maillard products) (Chevance et al., 2000).

3.4. Sensory evaluation

The results of sensory evaluations are shown in Table 8. Sensory parameters acceptance changes were connected with changes caused by recipe modifications. The consumers showed different acceptance between the samples. Sensory evaluation showed that the most appreciated samples with modified composition were those with canola oil and β-glucan addition (O + B burgers). Acceptance of all sensory parameters of O + B samples was very similar to control burgers’ acceptance. The addition of β-glucan (B group) decreased the acceptance of most of the quality parameters (aroma, taste, texture, juiciness and overall acceptance) significantly (P < 0.05). A decrease of juiciness acceptance was also detected in samples with canola oil (O group). The results of work presented by Piñero et al. (2008) showed no influence of oat soluble fibres on the tenderness, appearance and colour acceptance of meat products. The study of Afshari et al. (2017), however, revealed that barley β-glucan does not change the overall acceptability and colour of sausages.

4. Conclusions

The obtained results showed that the addition of canola oil and β-glucan as tallow replacements in beef burgers significantly improved the quality of fatty acid profile and, by consequence, changed the profile of volatile compounds. The consumption of one portion (150 g) of product with canola oil and β-glucan addition can provide 57.6% of the daily amount of linolenic acid (C18:3n3). This strategy improves not only the nutritional value but also the sensory properties and consumer acceptance of functional low-fat meat products. Thus, there is potential in the use of canola oil and β-glucan for the creation of functional low-fat beef products with acceptable volatile compound and beneficial fatty acid profiles.

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Conflict of interest

The authors declare no conflict of interest.

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