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Improving the quality of sous-vide beef from Holstein-Friesian bulls by different marinades

Katarzyna Tkacz[1*], Monika Modzelewska-Kapituła[1], Massimiliano Petracci[2] Weronika Zduńczyk[1]

[1]Department of Meat Technology and Chemistry, Faculty of Food Sciences, University of Warmia and Mazury in Olsztyn, Plac Cieszyński 1, 10-719 Olsztyn, Poland

[2]Department of Agricultural and Food Sciences, Alma Mater Studiorum, University of Bologna, Piazza Goidanich 60, 47521 Cesena, Italy

*corresponding author: Department of Meat Technology and Chemistry, Faculty of Food Sciences, University of Warmia and Mazury in Olsztyn, Plac Cieszyński 1, 10-719 Olsztyn, Poland, e-mail: ktkacz@uwm.edu.pl;

Abstract

The aim of the study was to determine effects of four commercial marinades on the colour, tenderness, cooking loss and sensory characteristics of *semimembranosus* beef muscles before and after sous-vide (SV) treatment. Muscles (n = 24) were marinated using Odessa (O; red pepper, garlic, onion), Mexico (M; red pepper, tomato), Old Polish (OP; pepper, garlic), and Bordeaux (B; pepper, red pepper, garlic) marinades for 24h at 4°C. Marinades uptake ranged from 3.3% (M) to 4.4% (B). Marinating and SV significantly affected all colour parameters. In SV beef, the highest values of L* were noted in OP and O samples, whereas the highest a* and b* values in M samples. Overall, marinating reduced ($P<0.05$) cooking loss (34.6%) and shear force (19.5%). The use of marinating prior to SV treatment beneficially affected taste, tenderness and juiciness of beef. OP marinade allowed to obtain beef steaks with the best sensory quality and the lowest shear force.

Keywords: Beef quality; Marinating; Sensory quality; Sous-vide; Taste; Texture

1. Introduction

The beef obtained from the Holstein-Friesian cattle breed, which is considered as the most important dairy breed worldwide, is predominant in the Polish market. The beef is produced mainly from heifers, which are not suitable for complementing a dairy cattle herd, and young bull's carcasses. Therefore, beef producers have difficulties in offering the meat with consistent quality traits (tenderness, juiciness and taste) to consumers. The improvement of the beef quality and its repeatability is the aim of studies conducted by many research groups in Poland and all over the World (Isleroglu, Kemerli, & Kaymak-Ertekin, 2015; Lizaso, Beriain, Horcada, Chasco, & Purroy, 2011; Macharáčková et al., 2021; Modzelewska-Kapituła, Tkacz, Nogalski, Karpińska-Tymoszczyk, & Więk, 2019; Supaphon et al., 2021; Węglarz, 2010; Wyrwisz et al., 2016; Yang et al., 2021). The issue is of vital importance because of recent trends in meat consumption where price will be not the most important factor for purchasing, whereas high and repeatable quality (nutritional value, sensory, and hygienic quality) is going to be the most important (Henchion, McCarthy, Resconi, & Troy, 2014; Listrat et.al., 2020a; Żakowska-Biemans et. al., 2017).

The beef palatability is basically determined by three quality attributes, which are perceived during meat consumption taste, tenderness and juiciness (Henchion, McCarthy, Resconi, & Troy, 2014; O'Quinn, Legako, Brooks, & Miller, 2018; Pogorzelski, Woźniak, Polkinghorne, Półtorak, & Wierzbicka, 2020). These attributes are known to vary and to be influenced by many factors, including the animal production - breed, genetics, diet, animal age, handling stress, etc.; carcass treatment - quality grade, marbling, aging, electrical stimulation, chilling methods, carcass suspension method, product enhancement, etc.; final preparation and cooking procedures applied to the product (Naqvi et al., 2021; O'Quinn, Legako, Brooks, & Miller, 2018; Pogorzelski, Woźniak, Polkinghorne, Półtorak, & Wierzbicka, 2020). Tenderness is a well-known multifactorial sensory trait which is, determined by the complex interaction of ante-mortem and post-mortem factors and it, has the greatest impact on consumer satisfaction (Lawrence, & Lawrence, 2021; Listrat et al., 2020b; Naqvi et al., 2021; Żakowska-Biemans et al., 2017). In the last years, there have been many attempts to improve it. The studies, their conclusions and detailed guidelines made it possible by introducing changes in the production practice and developing new technologies for improving tenderness and consumer satisfaction (Liu et al. 2020; O'Quinn, Legako, Brooks, & Miller, 2018). O'Quinn, Legako, Brooks, and Miller (2018) pointed out that consumers who are satisfied with the beef tenderness pay more attention to the meat's taste. Indeed, it was showed that the taste accounted for 49.4% of overall beef palatability, whereas the tenderness and juiciness accounted for 43.4% and 7.4, respectively (O'Quinn, Legako, Brooks, & Miller, 2018). Similarly, Liu et al. (2020) showed that for European consumers who evaluated beef samples originated from France, Poland, Ireland and Northern Ireland, which differed in terms of cattle breed, hang method, aging time, muscle cut and cooking method (to guarantee a large variation in the beef palatability and consumer response), the most important attributes were taste (39%), and tenderness (31%), followed by juiciness (24%). Moreover, cooking method and carcass cut affected the impact of the tenderness, juiciness and flavour liking to overall liking variability.

The cooking method is considered the last component in the process of shaping the final quality of beef. The available literature indicates that an appropriate selection of final cooking method is vitally important for beef tenderness, taste and juiciness, and it should be chosen individually for each (Guzek et al., 2015; Liu et al., 2020; Macharáčková et al., 2021). As it was shown by Guzek et al. (2015), the most suitable cooking method for tenderloin, which produced meat with the best sensory properties, was grilling, whereas Macharáčková et al. (2021) reported that roasting in convection oven is the most appropriate method for striploin (whole cut).

It should be noted that in order to improve the tenderness and juiciness of different meat types (Dominguez-Hernandez, Salaseviciene, & Ertbjerg, 2018), especially beef (Modzelewska-Kapituła Pietrzak-Fiećko. Tkacz, Draszanowska, & Więk, 2019; Naqvi et al., 2021; Supaphon et al., 2021; Uttaro & Zawadski, 2019), the use of sous-vide treatment is recommended. It is a low-temperature long-time (LTLT) cooking technique, which involves cooking of raw meat in vacuum-sealed heat-stable bags. The cooking is conducted at temperatures ranging from 55 to 95°C for several hours to several days depending on the meat type, thickness and the amount of connective tissue, followed by a rapid cooling (Ayub, & Ahmad, 2019; Baldwin, 2012; Ortuno, Mateo, Rodríguez-Estrada, & Banón, 2021). The sous-vide meat not only has a better sensory properties, including uniform and cohesive structure, but also a better preserved nutritional quality (Naqvi et al., 2021). Therefore, the technique is used in gastronomy, meat industry and even in households. It is frequently used for beef preparation because it enables to limit the differences in tenderness between products obtained from cattle differed in age and gender, as well as diverse aging time (Naqvi et al., 2021; Botinestean, Keenan, Kerry, & Hamill, 2016; Dominguez-Hernandez, Salaseviciene, & Ertbjerg, 2018). However, the sous-vide treatment parameters such as temperature and time should be carefully adjusted, to obtain the uniform product from an uneven raw material.

In our previous work (Modzelewska-Kapituła, Tkacz, & Nogalski, et al., 2021), the attempt to make the eating quality of *semitendinosus* (SM) muscle (obtained from Holstein-Friesian bulls) more attractive had been made. These muscles are attractive for consumers because of their uniform colour and structure, however they are less tender than e.g. *longissimus lumborum* (LL) when cooked in a traditional way. It was shown that SM and LL muscles after 14-d ageing and sous-vide treatment (60°C, 4h) were characterized by similar eating quality, including tenderness and juiciness. However, it was also noted that it would be beneficial from a consumer perspective to improve taste and aroma acceptability by e.g. an appropriate selection of spices. One of the possible ways to increase the sensory quality, including taste acceptability, is marinating (Pérez-Juan, Kondjoyan, Picouet, & Realini, 2012; Petracci et al., 2012; Yusop, O'Sullivan, & Kerry, 2011). The treatment is defined as a soaking of the raw meat in a mixture of spices and different liquid food products e.g. wine, beer, vinegar, fermented dairy beverages, oils with the addition of plant extracts and herbs, in order to increase meat tenderness, taste and aroma, as well as to prolong the product's shelf-life and its safety (Cordeiro et al., 2020; Goli, Bohuon, Ricci, Trystram, & Collignan, 2011; Sengun et al., 2021). To meet consumers demands according more natural meat products, many researchers use natural ingredients such as juices from lemon, pineapple, potato, lime, berries, raspberries and strawberries in the marinades due to their antioxidant properties (Khan, Busquets, & Azam, 2021; Latoch, & Libera, 2019; Petracci et al., 2012). Under commercial conditions, marinades are based on water–oil emulsions containing sodium chloride, polyphosphates, lactates, sugars, spices, organic acids, functional additives (e.g. xanthan and guar gum), antimicrobial agents (sorbate and/or benzoate) and aroma enhancers (Goli, Bohuon, Ricci, Trystram, & Collignan, 2011; Pérez-Juan, Kondjoyan, Picouet, & Realini, 2012; Yusop, O'Sullivan, Kerry, & Kerry, 2010). The salt increases the water holding capacity, whereas the phosphates increase pH value, water holding capacity and the production yield (Goli, Bohuon, Ricci, Trystram, & Collignan, 2011; Pérez-Juan, Kondjoyan, Picouet, & Realini, 2012; Sengun et al., 2021). Acid marinades increase meat tenderness by lowering meat pH, which in turn results in weakening the muscle structure, intensification of the proteolysis by cathepsins and elevated collagen conversion into gelatine (Cordeiro et al., 2020; Sengun et al., 2021). According to the authors best knowledge there are no papers describing the effect of commercially available marinades, which might be used in both meat processing plants and households, on the quality of sous-vide beef from dairy breeds. Therefore, to fill the gap and to continue our previous work on increasing the eating quality of beef, the study was undertaken to determine the effect of different commercial marinades and sous-vide treatment on the colour, tenderness, cooking loss and sensory characteristics of *semimembranosus* beef muscles.

2. Materials and methods

2.1. Raw material preparation

In the study, *semimembranosus* (n = 24) muscles, obtained from carcasses of Polish Holstein-Friesian bulls (20.5 ± 2 months) were used. Bulls were farmed under controlled conditions in Agricultural Experiment Station in Bałcyny (Poland). The protocol for animal research was approved by the Ethics Committee of the University of Warmia and Mazury (Decision No. 8/2020). Young bulls were reared in a traditional system, using milk replacer, hay and concentrate. Starting from the 6th month of age, animals were fattened semi-intensively and they were fed *ad libitum* a total mixed ration (TMR) composed of maize silage plus 2 kg concentrate to 15th month of age when they started to receive TMR plus 3.5 kg concentrate. The concentrate composition was: rapeseed meal 15%, triticale meal 82.5% and premix 2.5%. Commercial mineral-vitamin premix for fattening cattle (code of product 7619; Cargill Poland Ltd., Warsaw, Poland) consisting of per kg: Ca, 235 g; Na, 79 g; P, 48 g; Mg, 28 g; Fe, 500 g; Mn, 2000 mg; Cu, 375 mg; Zn, 3750 mg; J, 50 mg; Co, 12.5 mg; Se, 12.50 mg; vitamin A, 250,000 IU; vitamin D3, 50,000 IU; vitamin E, 1000 mg; dl-alpha-tocopherol, 909.10 mg. The fattening was finished when the bulls reached 600 kg of body weight. They were then transported to a meat processing plant, where they were kept in individual boxes with access to water for 15 to 20 hours. Slaughter and post-slaughter processing were carried out in accordance with Council Regulation (EC) No 1099/2009 of 24 September 2009 (Council Regulation, 2009) on the protection of animals at the time of killing. Muscles were removed at 24 h post-mortem from left half-carcass of each animal and delivered to a laboratory in a cooling box at refrigerated temperature. The muscles were kept in the refrigerated temperature (4 ± 1°C) overnight. Each cut was packed individually in a vacuum pouch (PA/PE, thickness 70 µm, Inter Arma sp. z o.o., Rudawa, Poland), which were then heat-sealed. The vacuum-packaged meat was stored to 14th day post-mortem at 4 ± 1°C in a climate chamber (Memmert GmbH, Schwabach, Germany). After that the muscles were split randomly into 4 groups, 6 muscle in each group. From each muscle two 2.5-cm thick steaks weighing approx. 200 g were cut and a sample of beef approx. 200 g for chemical analyses. One steak was subjected to marinating in a particular marinade and the other represented unmarinated control (were investigated immediately). In the study 4 different commercial marinades (Amco Sp. z o.o., Dybów-Kolonia, Poland) were used: Odessa, Mexico, Old Polish, and Bordeaux. They were used according to the producer recommendations in the quantity of 80 g per 1 kg of meat. The marinade composition, colour and pH are shown in Table 1. For each sample, the appropriate amount of marinade was applied (on each side) and the samples were marinated in separate plastic containers with lids for 24 h at 4°C. Subsequently, the samples were weighed and vacuum-packed and subjected to sous vide treatment using Fusion Chef by Julabo Diamond Z (Julabo GmbH, Seelbach, Germany) at 60°C for 4 h according to a recommendation for beef (Baldwin, 2012). After that, the packages were cooled down in a cold water and subjected to analyses.

2.2. Proximate composition

A portion of approx. 200 g of beef after 14-d ageing was ground twice using a 3 mm mesh and then thoroughly manually mixed. The proximate composition was determined – moisture (PN-ISO1442, 2000), fat (AOAC no 991.36, 2006a), protein (AOAC no 992.15, 2006b) and ash (PN-ISO 936, 2000) contents.

2.3. pH measurements

Values of pH were measured with a combined electrode FC 200 and pH-meter HI 8314 (Hanna Instruments Polska, Olsztyn, Poland) in 8% marinades solutions (concentration as in marinating) and directly in beef steaks. The device was first calibrated using pH 7 and pH 4 buffers. The pH values were determined in triplicate for each sample.

2.4. Colour determination

The colour of the marinades was measured immediately before marinating, while the colour of beef was measured before marinating (on the freshly cut surface of steaks after 60-min blooming), after marinating and after sous-vide treatment according to the procedure described by Modzelewska-Kapituła, Tkacz, and Nogalski (2021). The colour in CIE L*a*b* system was measured using a MiniScan XE Plus device (HunterLab, Reston, USA) with standard illuminant D65, a 10° standard observer angle and a 2.54-cm-diameter aperture, in three different locations of the surface of each sample.

2.5. Marinade uptake and cooking loss

The beef steaks were weighed before and after marinating and after sous-vide treatment. Based on the mass differences, the marinade uptake and cooking loss were calculated and expressed in percentages.

2.6. Warner-Bratzler shear force (WBSF) assessment

From each sous-vide beef sample (non-marinated and marinated) the samples for WBSF determination were cut parallel to the longitudinal orientation of the muscle fibres after overnight chilling (3 ± 1°C). The analysis was carried out on samples (10 mm x 10 mm, about 40 mm long, n = 5 from each steak) at room temperature (approx. 20°C). The samples were cut perpendicular to the longitudinal orientation of the muscle with a shear blade with a triangular aperture of 60° (load 500 N, head speed 200 mm/min, Instron 5942, Instron, Norwood, USA).

2.7. Sensory analysis

The sensory analysis was performed on marinated with four different commercial marinades beef samples and non-marinated controls according to the procedure described in Modzelewska-Kapituła et al. (2021). Briefly, the samples were cut into approx. 2-mm thick slices, coded with three-digit numbers, and served to panellists (n=6, trained for 36 h, non-smokers, females) at an ambient temperature randomly on white plates. The evaluation was carried out in the sensory laboratory of Meat Technology and Chemistry Department at room temperature of approximately 20°C, under white fluorescent lighting. Water and bread were provided for cleansing the palate. In total, 8 sensory analysis sessions were performed during which 6 meat samples was evaluated. Panellists scored each sample for colour uniformity (1, very uneven, 10, entirely even), aroma intensity (1, imperceptible; 10, extremely intense) and its acceptability (1, not acceptable; 10, very desirable), juiciness (1, extremely dry; 10, extremely juicy), tenderness (1, extremely tough; 10, extremely tender), meat taste as well as spicy taste intensities (1, imperceptible; 10, extremely intense), taste acceptability (1, not acceptable; 10, very desirable), and overall acceptability (1, not acceptable; 10, very desirable) using a structured scale.

2.8. Data analysis

The results were presented as mean values and standard error of the mean. To examine the effect of marinating and marinade type on the colour, WBSF, cooking loss and sensory quality, two-way Anova was applied. To determine the differences between mean values obtained for different marinades, excluding sensory analysis results, an analysis of variance was conducted, and Duncan's test. To compare sensory analysis results, non-parametric Kruskal-Wallis test was used. The significance level was set at 0.05. Cluster analysis was used to classify objects into groups using data from WBSF determination, cooked meat colour (L*, a*, b*), and cooking loss. The analysis was performed using a Euclidean distance as a measure of the proximity between samples and a variable linkage using a k-means method. Statistical analysis was performed using Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA., USA) software.

3. Results

3.1. Beef composition and marinades absorption

The material for the study was *semimembranosus* muscle containing approx. 74.7% moisture, 22.4% protein, 1.2% fat, 1.2% ash, and having a pH of 5.6. The chemical composition was typical for lean beef and similar to that noted in previous studies (Lizaso, Beriain, Horcada, Chasco, & Purroy, 2011; Modzelewska-Kapituła et al., 2018; Wyrwisz et al. 2016). The pH value was typical for normal quality meat, without Dark-Firm-Dry defect (Lizaso, Beriain, Horcada, Chasco, & Purroy, 2011; Yang et al., 2021). The marinade uptake ranged from 3.3 % (Mexico) to 4.4% (Bordeaux), with the mean absorption yield of 3.9% and was dependent on the type of functional additives in the recipe - a gel forming agent in Mexico and hydrolysed plant protein in Bordeaux, the specificity of which is discussed in next part. Similar results were reported by Sengun et al. (2021) for an acid marinade used for beef marinating (from 3.0% to 4.0%), and Yusop, O'Sullivan, Kerry, and Kerry (2012) for a Chinese marinade used for chicken marinating (from 5.0% to 5.4%). A higher marinade absorption, as a result the differences in the osmotic pressure exerted by different natural marinades and their quantity, was noted for fermented beverage-based marinades such as acid whey and buttermilk used for marinating chicken meat (6.5% and 7.7%, respectively) (Augustyńska-Prejsnar, Sokołowicz, Hanus, Ormian, & Kačániová, 2020). ~~whereas lower when piri-piri marinade was used for pork preparation (from 2.2% to 2.9%) (O'Neill, Cruz-Romero, Duffy, & Kerry, 2019).~~

3.2. The influence of marinating and marinade type on the colour

The colour of raw beef before and after marinating as well as the colour of marinated and non-marinated beef after sous-vide treatment is shown in Table 2. As expected, processing procedures such as marinating and cooking significantly affected all colour parameters ($P <$ 0.001). Marinating of raw beef caused a decrease in L* and a* values, and an increase in b* values, which was likely due by marinades components especially in the Old Polish marinade, in which the addition of pepper and garlic resulted in the a * 5.63 and b * as much as 43.39 (Table 1). However, after sous-vide treatment L* increased (but still it was lower than in raw beef), a* decreased, whereas b* remained similar compared to raw marinated steaks. The influence of marinating on the colour of sous-vide beef was clearly showed – marinades decreased L* and increased b* values as compared to beef subjected to sous-vide without marinating. The differences between sous-vide and marinated sous-vide, were caused by the colour of the marinades stemmed from components used in the formulations (Table 1), similarly as it was noted in the raw beef. The sous-vide treatment, in both marinated and non-marinated samples, affected significantly the redness of beef, and a reduction in a* values before and after sous-vide was noticed. A similar was reported by O'Neill, Cruz-Romero, Duffy, and Kerry (2019) as a result of cooking piri-piri marinated pork. Changes in the redness were primary caused by the denaturation of myoglobin on the surface of beef steaks resulted from heating, and in the case of marinated samples additionally by spices being marinades components, especially red pepper and tomato, which in the Mexico marinade resulted in an a* of 29.93 (Table 1).

As a result of colour differences between samples, chroma and hue differed as well. It was noted that marinating significantly decreased chroma, both in raw and sous-vide steaks. Chroma (C*) being an indicator of colour saturation, refers to the myoglobin concentration and its form (Sánchez del Pulgar, Gazquez, & Ruiz-Carrascal, 2012). The higher C* values, the higher concentration of myoglobin and lower content of denatured myoglobin (Ledward, 1992). Marinades used in this study, apart from components which directly affected beef colour such as red pepper and tomato, contained also salt, which might act as a pro-oxidant by leading to lower C* values, likely caused also by denaturation of the myoglobin in a raw marinated beef. All treatments differed ($P < 0.001$) in terms of hue angle (h˜). Generally, sous-vide samples (marinated and non-marinated) had higher values than raw samples, and marinated samples (both raw and cooked) showed higher values than those non-marinated (Table 2). Hue angle determines the tone of colour and depends on yellowness and redness values. As a result of marinating, the colour of beef before cooking switched from red toward more orange, which was further escalated by thermal treatment and as a result the highest values of hue were noted in marinated sous-vide steaks.

Marinade type affected all of colour parameters in sous-vide beef ($P < 0.001$, Table 3). The highest value of L* was noted in Old Polish and Odessa marinated samples, whereas the highest a* and b* values in Mexico samples. These differences resulted from a diverse composition of marinades, e.g. presence of red pepper and tomato. Red pepper contains a high concentration of carotenoids and is wildly used in the food industry as a natural colorant in sauces, soups and meat dishes. It is added also to marinades to obtain a desirable colour of meat (Yusop et al., 2012). Red pepper was present in three out of four marinades used in the study: Odessa, Mexico and Bordeaux, and therefore in these samples higher a* values were noted as compared with the samples treated with Old Polish marinade, which did not contain red pepper. Moreover, Mexico marinade contained also tomato, which increased yellowness as demonstrated in the highest b* values in these samples. Yusop et al. (2012) reported a similar effect of paprika oleoresin on a marinated poultry meat colour as noted in this study, resulting in a decrease in L* and an increase in a*. Moreover, it was shown that the effect depended on the concentration of the paprika oleoresin in a marinade.

Beef marinated with Bordeaux had lower chroma than the remaining samples. It was noted that hue angle increased with the decrease in a* values (Table 1, 3) and the highest hue angle was noted in Old Polish marinated steaks, which had the lowest a* values. A similar relations was noted also by Sánchez del Pulgar, Gazquez, and Ruiz-Carrascal (2012).

The ΔE coefficient is an indicator of the colour change and here it was calculated between raw non-marinated beef and the beef subjected to marinating and sous-vide. Based on values obtained, ranging from 9.0 to 16.5, it can be concluded that changes in the beef colour were obvious even for an unexperienced observer because values exceeded 2 (*CIE 1978).* The higher ΔE values, the greater and more perceived by consumers changes in beef colour. The marinade which caused the smallest changes was Mexico by resulting from a mixture of two intensely red spices - red pepper and tomato.

3.3. The influence of marinating and marinade type on cooking loss and WBSF values

Overall, marinating reduced cooking loss ($P < 0.001$, Table 4) of 34.6% as well reduced WBSF values of sous-vide beef ($P < 0.001$, Table 4) of 19.5%. The marinade which had the most tenderizing effect was Old Polish, whereas the remaining marinades showed a similar effect. The cooking loss noted in Odessa and Bordeaux (containing hydrolysed plant protein) marinated samples was lower compared with samples marinated with Mexico and Old Polish. Components of marinades such as hydrolysed plant protein, stabilizers, a gel forming agent, salt and sugar, are recognized as the first category of functional ingredients of marinades, which affect water holding capacity and textural properties of meat via changes in the ionic strength (Yusop, O'Sullivan, & Kerry, 2011). Due to the ionic properties of salts and other compounds, the number of charged sites and spaces between protein molecules increase, which beneficially affects water holding capacity. Marinade compounds diffuse through sarcolemma and cause a myofibrils swell, and later the extraction and solubilisation of myofibrillar proteins. The mixture of solubilized proteins and sarcoplasmic fluid form a specific protein matrix which after heating becomes a gel matrix which holds water and affects the meat texture (Żochowska-Kujawska et al., 2012; Latoch, 2020; O'Neill, Cruz-Romero, Duffy, & Kerry, 2019). As a result, up to 10% of water can be retained in the meat during the marinating process (as a marinade absorption) (Yusop, O'Sullivan, & Kerry, 2011) and cooking loss is reduced - just as it was noted in this study.

A similar cooking loss to that noted in this study (from 17% to 21%) was reported by O'Neill, Cruz-Romero, Duffy, and Kerry (2019) for piri-piri marinated pork (17% to 19%) and Yusop et al. (2012) for poultry meat marinated using paprika oleoresin (19% to 22%). A higher cooking loss from 24% up to 29% was reported in studies where acid marinades such as fermented beverages, lime juice and pineapple puree, and a Chinese marinade were used

(Augustyńska-Prejsnar, Sokołowicz, Hanus, Ormian, & Kačániová, 2020; Lawrence & Lawrence, 2021).

The increase in the meat tenderness noted in this study resulted from marinades uptake by muscle tissue and beneficial changes in muscle proteins and was also reported by previous studies (Augustyńska-Prejsnar, Sokołowicz, Hanus, Ormian, & Kačániová, 2020; Sengun et al., 2019; Pérez-Juan, Kondjoyan, Picouet, & Realini, 2012). Latoch (2020) showed that marinating a meat in buttermilk or yoghurt for 6 or 9 days and then sous-vide cooking at 60°C for 6 h increased its tenderness which was demonstrated by a decrease in hardness and chewiness of pork loins. Similarly, Żochowska-Kujawska et al. (2012) reported a beneficial impact of marinating using a wine, lemon juice, kefir and pineapple juice on a wild boar and deer meat texture. As a result of 7-d marinating, the toughness of muscles treated with a wine decreased about 24% to 28%, whereas using lemon and pineapple juices and kefir decreased the tenderness about 30% to 36%; 44% to 50% and 35% to 41%, respectively, compared to control samples. Also, Lawrence and Lawrence (2021) in their research reported that WBSF was reduced by 7 to 24% via a treatment combining a blade tenderization and marination using lime juice or pineapple puree. Moreover, Sengun et al. (2019) showed that, rosehip vinegar was effective in reducing the hardness value of meat.

Based on the classification of the beef tenderness proposed by Destefanis, Brugiapaglia, Barge, and Dal Molin (2008), beef is considered tender if the WBSF ranges from 32.96 to 42.77 N. Thus, it can be pointed out that the use of sous-vide as a method of thermal treatment enabled obtaining a tender beef, which in the case of the beef produced from dairy breeds might be challenging. In turn, marinated sous-vide beef, may be classified as very tender as if all marinades enabled to obtain WBSF below 32.96 N (Destefanis, Brugiapaglia, Barge, & Dal Molin, 2008), which shows beneficial effect of marinating on beef tenderness.

3.4. The influence of marinating and marinade type on the sensory quality

The use of marinating prior to sous-vide treatment beneficially affected all sensory quality attributes, with the exception of meat aroma intensity and acceptability which were not affected by marination (Table 4). Both, non-marinated and marinated sous-vide samples were scored relatively high, which indicates good eating quality of beef. Interestingly, marinating increased the surface colour uniformity score ($P < 0.001$), which indicates that using the treatment improves not only the taste, tenderness and juiciness of beef, but also its appearance.

The effect of marinade type on the sensory quality of beef was noted (Table 4, $P < 0.001$), and resulted from different composition of marinades used in this study. The colour uniformity was scored the highest in Bordeaux marinated steaks, lower in Mexico and Old Polish samples, whereas the lowest in Odessa samples. More intense and acceptable aroma was noted in Mexico, Old Polish and Bordeaux than in Odessa samples. Using Old Polish and Bordeaux marinades increased the juiciness of beef as compared with Odessa and Mexico. Differences in the tenderness were noted only between Mexico and Bordeaux marinades, with the latter producing steaks less tender. Marinating using Old Polish resulted in higher meat taste intensity than Odessa and Bordeaux, whereas spice taste intensity was scored higher in Mexico and Bordeaux samples than Old Polish and Odessa, with the latter being the least spicy.

An improvement in selected sensory attributes of marinated sous-vide beef in respect to non-marinated sous-vide samples is shown in Fig. 1. It is clearly shown that not all of tested marinades increased the taste acceptability. The Odessa marinade, which contained apart from red pepper and garlic (these components were in all marinades used) also onion, did not enhance the colour, taste nor juiciness and affected beneficially only the tenderness of beef steaks. However, the remaining three marinades, enhanced all of sensory attributes, but to a different extend. Bordeaux marinade improved the colour about 31%, Mexico improved the tenderness about 14.4%, whereas Old Polish enhanced the meat taste intensity about 17.3%, the juiciness about 17.2% and the taste acceptability about 11.5%. The most acceptable taste and the highest score for overall acceptability had Old Polish and Bordeaux marinated beef. The beneficial impact of marinades on sensory quality resulted from the presences of spices such as pepper, red pepper, garlic, onion, spices extract and aromas, which belong to the second category of functional ingredients in marinades and improve the attractiveness of the marinated meat (Yusop, O'Sullivan, & Kerry, 2011; O'Neill, Cruz-Romero, Duffy, & Kerry, 2019). Moreover, these additives exhibit a strong anti-oxidant property, so they are beneficial from the product quality and an impact on the human health perspectives (Aguirrezábal, Mateo, Domi´nguez, & Zumalacárregui, 2000; Martini, Cattivelli, Conte, & Tagliazucchi, 2021; Ren, Nian, & Perussello, 2020; Zhang et al., 2021).

However, consumers differ in their preferences in terms of taste and aroma. Nevertheless, in the majority of studies a beneficial impact of marinades on the eating quality of meat was proved. O'Neill, Cruz-Romero, Duffy, and Kerry (2019) used piri-piri marinade (which contained rapeseed oil 60%, spices and flavourings 36% such as chili, garlic, jalapeno, black pepper, onion, paprika, lovage root, fenugreek seed, bird clover, onion leek, coriander, turmeric, ginger, cumin seed, fennel, sugar, grapefruit, passion fruit, papaya, mango, palm fat; and salt 4%) and reported that it enhanced the flavour acceptability of marinated pork chops subjected to high pressure processing. As expected, each marinade components exhibited a different impact on the eating quality of marinated meat in agreement with Sengun et al. (2019). They studied effects of organic fruit vinegars used in marinades for beef and reported that the highest scores in terms of flavour were noted in meat samples marinated with grape vinegar ($P > 0.05$). Additionally, it was pointed out that using vinegars as marinade components increases meat safety and quality (Sengun et al., 2019). Osaili et al. (2021) investigated an influence of marinating using yoghurt with an addition of active essential oils containing thymol, carvacrol, and cinnamaldehyde on the quality of camel meat and found that the highest scores of all examined sensory attributes were noted in samples with 1% and 2% cinnamon essential oil, which might be also used as an effective tool to decrease populations of *E. coli* O157:H7 and *Salmonella* spp. The marinating might be useful in improving the quality of meat obtained from older animals which might suffer from inadequate tenderness. As it was shown by Augustyńska-Prejsnar, Sokołowicz, Hanus, Ormian, and Kačániová (2020) marinating of breast muscles originated from carcasses of laying hens after the termination of the laying period, using buttermilk and whey enhanced ($P < 0.05$) the taste intensity and acceptability, aroma, and tenderness as compared with the control, and moreover, buttermilk-marinated meat showed the highest taste acceptability.

3.5. Cluster analysis

To determine similarities between sous-vide beef marinated with different commercial marinades, a cluster analysis was performed, using colour parameters: L*, a*, b*, cooking loss and WBSF values. As a result, a dendrogram was obtained (Fig. 2), in which clusters are visible - one connecting samples Odessa and Bordeaux, the next connecting this cluster with Mexico marinade. Further analysis revealed that samples marinated with Odessa, Bordeaux, and Mexico constituted one cluster (cluster 2), whereas beef marinated with Old Polish was identified as a separate cluster 1 (Fig. 3). The attribute which differentiated clusters, was WBSF, which was significantly lower for cluster 1 (Old Polish) thus indicating the best tenderness of Old Polish marinated samples.

4. Conclusions

Marinating *semimembranosus* muscle using commercial marinades containing red pepper, garlic, pepper, onion and tomato, beneficially affected the quality of sous-vide beef by improving the eating quality, including tenderness, and reducing cooking loss. The marinade which produced sous-vide beef with the best quality (the lowest WBSF and high scores for the juiciness, tenderness, meat taste acceptability and overall quality) was Old Polish. It was the only marinade used in this study which contained only garlic and pepper and on the contrary to the remaining marinades did not contain red pepper. The simple spices turned out to work the best in sous-vide beef. The results of this study have a potential for a practical application in terms of providing consumers guidelines for beef preparation using marinating and sous-vide to obtain highly acceptable products. The described way of preparing the beef using marinating and sous-vide cooking, might be used to make dished also for elderly people due to the fact that these treatments decrease an initial bite effort. Moreover, introducing marinated sous-vide beef as a ready-to-eat dish which would require only short heating before the consumption, would broaden the diversity of beef products in the market according to the assumption that the beef industry should ensure that the textural preferences of all population cohorts are provided for. Low cooking losses noted in this study in marinated sous-vide beef favourable affect the profitability of the production on the industrial scale.

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