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

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## 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

35 quality and its repeatability is the aim of studies conducted by many research groups in Poland  
36 and all over the World (Isleroglu, Kemerli, & Kaymak-Ertekin, 2015; Lizaso, Beriain, Horcada,  
37 Chasco, & Purroy, 2011; Macharáčková et al., 2021; Modzelewska-Kapituła, Tkacz, Nogalski,  
38 Karpińska-Tymoszczyk, & Więk, 2019; Supaphon et al., 2021; Węglarz, 2010; Wyrwicz et al.,  
39 2016; Yang et al., 2021). The issue is of vital importance because of recent trends in meat  
40 consumption where price will be not the most important factor for purchasing, whereas high  
41 and repeatable quality (nutritional value, sensory, and hygienic quality) is going to be the most  
42 important (Henchion, McCarthy, Resconi, & Troy, 2014; Listrat et.al., 2020a; Żakowska-  
43 Biemans et. al., 2017).

44 The beef palatability is basically determined by three quality attributes, which are perceived  
45 during meat consumption taste, tenderness and juiciness (Henchion, McCarthy, Resconi, &  
46 Troy, 2014; O'Quinn, Legako, Brooks, & Miller, 2018; Pogorzelski, Woźniak, Polkinghorne,  
47 Półtorak, & Wierzbicka, 2020). These attributes are known to vary and to be influenced by  
48 many factors, including the animal production - breed, genetics, diet, animal age, handling  
49 stress, etc.; carcass treatment - quality grade, marbling, aging, electrical stimulation, chilling  
50 methods, carcass suspension method, product enhancement, etc.; final preparation and cooking  
51 procedures applied to the product (Naqvi et al., 2021; O'Quinn, Legako, Brooks, & Miller,  
52 2018; Pogorzelski, Woźniak, Polkinghorne, Półtorak, & Wierzbicka, 2020). Tenderness is a  
53 well-known multifactorial sensory trait which is, determined by the complex interaction of ante-  
54 mortem and post-mortem factors and it, has the greatest impact on consumer satisfaction  
55 (Lawrence, & Lawrence, 2021; Listrat et al., 2020b; Naqvi et al., 2021; Żakowska-Biemans et  
56 al., 2017). In the last years, there have been many attempts to improve it. The studies, their  
57 conclusions and detailed guidelines made it possible by introducing changes in the production  
58 practice and developing new technologies for improving tenderness and consumer satisfaction  
59 (Liu et al. 2020; O'Quinn, Legako, Brooks, & Miller, 2018). O'Quinn, Legako, Brooks, and  
60 Miller (2018) pointed out that consumers who are satisfied with the beef tenderness pay more  
61 attention to the meat's taste. Indeed, it was showed that the taste accounted for 49.4% of overall  
62 beef palatability, whereas the tenderness and juiciness accounted for 43.4% and 7.4,  
63 respectively (O'Quinn, Legako, Brooks, & Miller, 2018). Similarly, Liu et al. (2020) showed  
64 that for European consumers who evaluated beef samples originated from France, Poland,  
65 Ireland and Northern Ireland, which differed in terms of cattle breed, hang method, aging time,  
66 muscle cut and cooking method (to guarantee a large variation in the beef palatability and  
67 consumer response), the most important attributes were taste (39%), and tenderness (31%),

68 followed by juiciness (24%). Moreover, cooking method and carcass cut affected the impact of  
69 the tenderness, juiciness and flavour liking to overall liking variability.

70 The cooking method is considered the last component in the process of shaping the final  
71 quality of beef. The available literature indicates that an appropriate selection of final cooking  
72 method is vitally important for beef tenderness, taste and juiciness, and it should be chosen  
73 individually for each (Guzek et al., 2015; Liu et al., 2020; Macharáčková et al., 2021). As it  
74 was shown by Guzek et al. (2015), the most suitable cooking method for tenderloin, which  
75 produced meat with the best sensory properties, was grilling, whereas Macharáčková et al.  
76 (2021) reported that roasting in convection oven is the most appropriate method for striploin  
77 (whole cut).

78 It should be noted that in order to improve the tenderness and juiciness of different meat  
79 types (Dominguez-Hernandez, Salaseviciene, & Erbjerg, 2018), especially beef  
80 (Modzelewska-Kapituła Pietrzak-Fiećko, Tkacz, Draszanowska, & Więk, 2019; Naqvi et al.,  
81 2021; Supaphon et al., 2021; Uttaro & Zawadski, 2019), the use of sous-vide treatment is  
82 recommended. It is a low-temperature long-time (LTLT) cooking technique, which involves  
83 cooking of raw meat in vacuum-sealed heat-stable bags. The cooking is conducted at  
84 temperatures ranging from 55 to 95°C for several hours to several days depending on the meat  
85 type, thickness and the amount of connective tissue, followed by a rapid cooling (Ayub, &  
86 Ahmad, 2019; Baldwin, 2012; Ortuno, Mateo, Rodríguez-Estrada, & Banón, 2021). The sous-  
87 vide meat not only has a better sensory properties, including uniform and cohesive structure,  
88 but also a better preserved nutritional quality (Naqvi et al., 2021). Therefore, the technique is  
89 used in gastronomy, meat industry and even in households. It is frequently used for beef  
90 preparation because it enables to limit the differences in tenderness between products obtained  
91 from cattle differed in age and gender, as well as diverse aging time (Naqvi et al., 2021;  
92 Botinestean, Keenan, Kerry, & Hamill, 2016; Dominguez-Hernandez, Salaseviciene,  
93 & Erbjerg, 2018). However, the sous-vide treatment parameters such as temperature and time  
94 should be carefully adjusted, to obtain the uniform product from an uneven raw material.

95 In our previous work (Modzelewska-Kapituła, Tkacz, & Nogalski, et al., 2021), the attempt  
96 to make the eating quality of *semitendinosus* (SM) muscle (obtained from Holstein-Friesian  
97 bulls) more attractive had been made. These muscles are attractive for consumers because of  
98 their uniform colour and structure, however they are less tender than e.g. *longissimus lumborum*  
99 (LL) when cooked in a traditional way. It was shown that SM and LL muscles after 14-d ageing  
100 and sous-vide treatment (60°C, 4h) were characterized by similar eating quality, including  
101 tenderness and juiciness. However, it was also noted that it would be beneficial from a

102 consumer perspective to improve taste and aroma acceptability by e.g. an appropriate selection  
103 of spices. One of the possible ways to increase the sensory quality, including taste acceptability,  
104 is marinating (Pérez-Juan, Kondjoyan, Picouet, & Realini, 2012; Petracci et al., 2012; Yusop,  
105 O’Sullivan, & Kerry, 2011). The treatment is defined as a soaking of the raw meat in a mixture  
106 of spices and different liquid food products e.g. wine, beer, vinegar, fermented dairy beverages,  
107 oils with the addition of plant extracts and herbs, in order to increase meat tenderness, taste and  
108 aroma, as well as to prolong the product’s shelf-life and its safety (Cordeiro et al., 2020; Goli,  
109 Bohuon, Ricci, Trystram, & Collignan, 2011; Sengun et al., 2021). To meet consumers demands  
110 according more natural meat products, many researchers use natural ingredients such as juices  
111 from lemon, pineapple, potato, lime, berries, raspberries and strawberries in the marinades due  
112 to their antioxidant properties (Khan, Busquets, & Azam, 2021; Latoch, & Libera, 2019;  
113 Petracci et al., 2012). Under commercial conditions, marinades are based on water–oil  
114 emulsions containing sodium chloride, polyphosphates, lactates, sugars, spices, organic acids,  
115 functional additives (e.g. xanthan and guar gum), antimicrobial agents (sorbate and/or benzoate)  
116 and aroma enhancers (Goli, Bohuon, Ricci, Trystram, & Collignan, 2011; Pérez-Juan,  
117 Kondjoyan, Picouet, & Realini, 2012; Yusop, O’Sullivan, Kerry, & Kerry, 2010). The salt  
118 increases the water holding capacity, whereas the phosphates increase pH value, water holding  
119 capacity and the production yield (Goli, Bohuon, Ricci, Trystram, & Collignan, 2011; Pérez-  
120 Juan, Kondjoyan, Picouet, & Realini, 2012; Sengun et al., 2021). Acid marinades increase meat  
121 tenderness by lowering meat pH, which in turn results in weakening the muscle structure,  
122 intensification of the proteolysis by cathepsins and elevated collagen conversion into gelatine  
123 (Cordeiro et al., 2020; Sengun et al., 2021). According to the authors best knowledge there are  
124 no papers describing the effect of commercially available marinades, which might be used in  
125 both meat processing plants and households, on the quality of sous-vide beef from dairy breeds.  
126 Therefore, to fill the gap and to continue our previous work on increasing the eating quality of  
127 beef, the study was undertaken to determine the effect of different commercial marinades and  
128 sous-vide treatment on the colour, tenderness, cooking loss and sensory characteristics of  
129 *semimembranosus* beef muscles.

130

## 131 **2. Materials and methods**

### 132 **2.1. Raw material preparation**

133 In the study, *semimembranosus* (n = 24) muscles, obtained from carcasses of Polish  
134 Holstein-Friesian bulls (20.5 ± 2 months) were used. Bulls were farmed under controlled  
135 conditions in Agricultural Experiment Station in Bałcyny (Poland). The protocol for animal

136 research was approved by the Ethics Committee of the University of Warmia and Mazury  
137 (Decision No. 8/2020). Young bulls were reared in a traditional system, using milk replacer,  
138 hay and concentrate. Starting from the 6<sup>th</sup> month of age, animals were fattened semi-intensively  
139 and they were fed *ad libitum* a total mixed ration (TMR) composed of maize silage plus 2 kg  
140 concentrate to 15<sup>th</sup> month of age when they started to receive TMR plus 3.5 kg concentrate. The  
141 concentrate composition was: rapeseed meal 15%, triticale meal 82.5% and premix 2.5%.  
142 Commercial mineral-vitamin premix for fattening cattle (code of product 7619; Cargill Poland  
143 Ltd., Warsaw, Poland) consisting of per kg: Ca, 235 g; Na, 79 g; P, 48 g; Mg, 28 g; Fe, 500 g;  
144 Mn, 2000 mg; Cu, 375 mg; Zn, 3750 mg; J, 50 mg; Co, 12.5 mg; Se, 12.50 mg; vitamin A,  
145 250,000 IU; vitamin D3, 50,000 IU; vitamin E, 1000 mg; dl-alpha-tocopherol, 909.10 mg. The  
146 fattening was finished when the bulls reached 600 kg of body weight. They were then  
147 transported to a meat processing plant, where they were kept in individual boxes with access to  
148 water for 15 to 20 hours. Slaughter and post-slaughter processing were carried out in accordance  
149 with Council Regulation (EC) No 1099/2009 of 24 September 2009 (Council Regulation, 2009)  
150 on the protection of animals at the time of killing. Muscles were removed at 24 h post-mortem  
151 from left half-carcass of each animal and delivered to a laboratory in a cooling box at  
152 refrigerated temperature. The muscles were kept in the refrigerated temperature ( $4 \pm 1^\circ\text{C}$ )  
153 overnight. Each cut was packed individually in a vacuum pouch (PA/PE, thickness 70  $\mu\text{m}$ , Inter  
154 Arma sp. z o.o., Rudawa, Poland), which were then heat-sealed. The vacuum-packaged meat  
155 was stored to 14<sup>th</sup> day post-mortem at  $4 \pm 1^\circ\text{C}$  in a climate chamber (Memmert GmbH,  
156 Schwabach, Germany). After that the muscles were split randomly into 4 groups, 6 muscle in  
157 each group. From each muscle two 2.5-cm thick steaks weighing approx. 200 g were cut and a  
158 sample of beef approx. 200 g for chemical analyses. One steak was subjected to marinating in  
159 a particular marinade and the other represented unmarinated control (were investigated  
160 immediately). In the study 4 different commercial marinades (Amco Sp. z o.o., Dybów-  
161 Kolonia, Poland) were used: Odessa, Mexico, Old Polish, and Bordeaux. They were used  
162 according to the producer recommendations in the quantity of 80 g per 1 kg of meat. The  
163 marinade composition, colour and pH are shown in Table 1. For each sample, the appropriate  
164 amount of marinade was applied (on each side) and the samples were marinated in separate  
165 plastic containers with lids for 24 h at  $4^\circ\text{C}$ . Subsequently, the samples were weighed and  
166 vacuum-packed and subjected to sous vide treatment using Fusion Chef by Julabo Diamond Z  
167 (Julabo GmbH, Seelbach, Germany) at  $60^\circ\text{C}$  for 4 h according to a recommendation for beef  
168 (Baldwin, 2012). After that, the packages were cooled down in a cold water and subjected to  
169 analyses.

170

## 171 **2.2. Proximate composition**

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

176

## 177 **2.3. pH measurements**

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

182

## 183 **2.4. Colour determination**

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

191

## 192 **2.5. Marinade uptake and cooking loss**

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

196

## 197 **2.6. Warner-Bratzler shear force (WBSF) assessment**

198 From each sous-vide beef sample (non-marinated and marinated) the samples for WBSF  
199 determination were cut parallel to the longitudinal orientation of the muscle fibres after  
200 overnight chilling ( $3 \pm 1^\circ\text{C}$ ). The analysis was carried out on samples (10 mm x 10 mm, about  
201 40 mm long, n = 5 from each steak) at room temperature (approx.  $20^\circ\text{C}$ ). The samples were cut  
202 perpendicular to the longitudinal orientation of the muscle with a shear blade with a triangular  
203 aperture of  $60^\circ$  (load 500 N, head speed 200 mm/min, Instron 5942, Instron, Norwood, USA).



204

## 205 **2.7. Sensory analysis**

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

221

## 222 **2.8. Data analysis**

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

233

## 234 **3. Results**

### 235 **3.1. Beef composition and marinades absorption**

236 The material for the study was *semimembranosus* muscle containing approx. 74.7%  
237 moisture, 22.4% protein, 1.2% fat, 1.2% ash, and having a pH of 5.6. The chemical composition

238 was typical for lean beef and similar to that noted in previous studies (Lizaso, Beriain, Horcada,  
239 Chasco, & Purroy, 2011; Modzelewska-Kapituła et al., 2018; Wyrwisz et al. 2016). The pH  
240 value was typical for normal quality meat, without Dark-Firm-Dry defect (Lizaso, Beriain,  
241 Horcada, Chasco, & Purroy, 2011; Yang et al., 2021). The marinade uptake ranged from 3.3 %  
242 (Mexico) to 4.4% (Bordeaux), with the mean absorption yield of 3.9% and was dependent on  
243 the type of functional additives in the recipe - a gel forming agent in Mexico and hydrolysed  
244 plant protein in Bordeaux, the specificity of which is discussed in next part. Similar results were  
245 reported by Sengun et al. (2021) for an acid marinade used for beef marinating (from 3.0% to  
246 4.0%), and Yusop, O’Sullivan, Kerry, and Kerry (2012) for a Chinese marinade used for  
247 chicken marinating (from 5.0% to 5.4%). A higher marinade absorption, as a result the  
248 differences in the osmotic pressure exerted by different natural marinades and their quantity,  
249 was noted for fermented beverage-based marinades such as acid whey and buttermilk used for  
250 marinating chicken meat (6.5% and 7.7%, respectively) (Augustyńska-Prejsnar, Sokołowicz,  
251 Hanus, Ormian, & Kačániová, 2020). ~~whereas lower when piri-piri marinade was used for pork  
252 preparation (from 2.2% to 2.9%) (O’Neill, Cruz-Romero, Duffy, & Kerry, 2019).~~

253

### 254 **3.2. The influence of marinating and marinade type on the colour**

255 The colour of raw beef before and after marinating as well as the colour of marinated and  
256 non-marinated beef after sous-vide treatment is shown in Table 2. As expected, processing  
257 procedures such as marinating and cooking significantly affected all colour parameters ( $P <$   
258  $0.001$ ). Marinating of raw beef caused a decrease in  $L^*$  and  $a^*$  values, and an increase in  $b^*$   
259 values, which was likely due by marinades components especially in the Old Polish marinade,  
260 in which the addition of pepper and garlic resulted in the  $a^*$  5.63 and  $b^*$  as much as 43.39  
261 (Table 1). However, after sous-vide treatment  $L^*$  increased (but still it was lower than in raw  
262 beef),  $a^*$  decreased, whereas  $b^*$  remained similar compared to raw marinated steaks. The  
263 influence of marinating on the colour of sous-vide beef was clearly showed – marinades  
264 decreased  $L^*$  and increased  $b^*$  values as compared to beef subjected to sous-vide without  
265 marinating. The differences between sous-vide and marinated sous-vide, were caused by the  
266 colour of the marinades stemmed from components used in the formulations (Table 1), similarly  
267 as it was noted in the raw beef. The sous-vide treatment, in both marinated and non-marinated  
268 samples, affected significantly the redness of beef, and a reduction in  $a^*$  values before and after  
269 sous-vide was noticed. A similar was reported by O’Neill, Cruz-Romero, Duffy, and Kerry  
270 (2019) as a result of cooking piri-piri marinated pork. Changes in the redness were primary  
271 caused by the denaturation of myoglobin on the surface of beef steaks resulted from heating,

272 and in the case of marinated samples additionally by spices being marinades components,  
273 especially red pepper and tomato, which in the Mexico marinade resulted in an  $a^*$  of 29.93  
274 (Table 1).

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

290 Marinade type affected all of colour parameters in sous-vide beef ( $P < 0.001$ , Table 3). The  
291 highest value of  $L^*$  was noted in Old Polish and Odessa marinated samples, whereas the highest  
292  $a^*$  and  $b^*$  values in Mexico samples. These differences resulted from a diverse composition of  
293 marinades, e.g. presence of red pepper and tomato. Red pepper contains a high concentration  
294 of carotenoids and is widely used in the food industry as a natural colorant in sauces, soups and  
295 meat dishes. It is added also to marinades to obtain a desirable colour of meat (Yusop et al.,  
296 2012). Red pepper was present in three out of four marinades used in the study: Odessa, Mexico  
297 and Bordeaux, and therefore in these samples higher  $a^*$  values were noted as compared with  
298 the samples treated with Old Polish marinade, which did not contain red pepper. Moreover,  
299 Mexico marinade contained also tomato, which increased yellowness as demonstrated in the  
300 highest  $b^*$  values in these samples. Yusop et al. (2012) reported a similar effect of paprika  
301 oleoresin on a marinated poultry meat colour as noted in this study, resulting in a decrease in  
302  $L^*$  and an increase in  $a^*$ . Moreover, it was shown that the effect depended on the concentration  
303 of the paprika oleoresin in a marinade.

304 Beef marinated with Bordeaux had lower chroma than the remaining samples. It was noted  
305 that hue angle increased with the decrease in  $a^*$  values (Table 1, 3) and the highest hue angle

306 was noted in Old Polish marinated steaks, which had the lowest  $a^*$  values. A similar relations  
307 was noted also by Sánchez del Pulgar, Gazquez, and Ruiz-Carrascal (2012).

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

315

### 316 **3.3. The influence of marinating and marinade type on cooking loss and WBSF values**

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

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

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

342 The increase in the meat tenderness noted in this study resulted from marinades uptake by  
343 muscle tissue and beneficial changes in muscle proteins and was also reported by previous  
344 studies (Augustyńska-Prejsnar, Sokołowicz, Hanus, Ormian, & Kačániová, 2020; Sengun et al.,  
345 2019; Pérez-Juan, Kondjoyan, Picouet, & Realini, 2012). Latoch (2020) showed that marinating  
346 a meat in buttermilk or yoghurt for 6 or 9 days and then sous-vide cooking at 60°C for 6 h  
347 increased its tenderness which was demonstrated by a decrease in hardness and chewiness of  
348 pork loins. Similarly, Żochowska-Kujawska et al. (2012) reported a beneficial impact of  
349 marinating using a wine, lemon juice, kefir and pineapple juice on a wild boar and deer meat  
350 texture. As a result of 7-d marinating, the toughness of muscles treated with a wine decreased  
351 about 24% to 28%, whereas using lemon and pineapple juices and kefir decreased the  
352 tenderness about 30% to 36%; 44% to 50% and 35% to 41%, respectively, compared to control  
353 samples. Also, Lawrence and Lawrence (2021) in their research reported that WBSF was  
354 reduced by 7 to 24% via a treatment combining a blade tenderization and marination using lime  
355 juice or pineapple puree. Moreover, Sengun et al. (2019) showed that, rosehip vinegar was  
356 effective in reducing the hardness value of meat.

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

364

### 365 **3.4. The influence of marinating and marinade type on the sensory quality**

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

372 The effect of marinade type on the sensory quality of beef was noted (Table 4,  $P < 0.001$ ), and  
373 resulted from different composition of marinades used in this study. The colour uniformity was

374 scored the highest in Bordeaux marinated steaks, lower in Mexico and Old Polish samples,  
375 whereas the lowest in Odessa samples. More intense and acceptable aroma was noted in  
376 Mexico, Old Polish and Bordeaux than in Odessa samples. Using Old Polish and Bordeaux  
377 marinades increased the juiciness of beef as compared with Odessa and Mexico. Differences in  
378 the tenderness were noted only between Mexico and Bordeaux marinades, with the latter  
379 producing steaks less tender. Marinating using Old Polish resulted in higher meat taste intensity  
380 than Odessa and Bordeaux, whereas spice taste intensity was scored higher in Mexico and  
381 Bordeaux samples than Old Polish and Odessa, with the latter being the least spicy.

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

400 However, consumers differ in their preferences in terms of taste and aroma. Nevertheless, in  
401 the majority of studies a beneficial impact of marinades on the eating quality of meat was  
402 proved. O'Neill, Cruz-Romero, Duffy, and Kerry (2019) used piri-piri marinade (which  
403 contained rapeseed oil 60%, spices and flavourings 36% such as chili, garlic, jalapeno, black  
404 pepper, onion, paprika, lovage root, fenugreek seed, bird clover, onion leek, coriander, turmeric,  
405 ginger, cumin seed, fennel, sugar, grapefruit, passion fruit, papaya, mango, palm fat; and salt  
406 4%) and reported that it enhanced the flavour acceptability of marinated pork chops subjected  
407 to high pressure processing. As expected, each marinade components exhibited a different

408 impact on the eating quality of marinated meat in agreement with Sengun et al. (2019). They  
409 studied effects of organic fruit vinegars used in marinades for beef and reported that the highest  
410 scores in terms of flavour were noted in meat samples marinated with grape vinegar ( $P > 0.05$ ).  
411 Additionally, it was pointed out that using vinegars as marinade components increases meat  
412 safety and quality (Sengun et al., 2019). Osaili et al. (2021) investigated an influence of  
413 marinating using yoghurt with an addition of active essential oils containing thymol, carvacrol,  
414 and cinnamaldehyde on the quality of camel meat and found that the highest scores of all  
415 examined sensory attributes were noted in samples with 1% and 2% cinnamon essential oil,  
416 which might be also used as an effective tool to decrease populations of *E. coli* O157:H7 and  
417 *Salmonella* spp. The marinating might be useful in improving the quality of meat obtained from  
418 older animals which might suffer from inadequate tenderness. As it was shown by  
419 Augustyńska-Prejsnar, Sokołowicz, Hanus, Ormian, and Kačániová (2020) marinating of breast  
420 muscles originated from carcasses of laying hens after the termination of the laying period,  
421 using buttermilk and whey enhanced ( $P < 0.05$ ) the taste intensity and acceptability, aroma, and  
422 tenderness as compared with the control, and moreover, buttermilk-marinated meat showed the  
423 highest taste acceptability.

424

### 425 **3.5. Cluster analysis**

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

435

### 436 **4. Conclusions**

437 Marinating *semimembranosus* muscle using commercial marinades containing red pepper,  
438 garlic, pepper, onion and tomato, beneficially affected the quality of sous-vide beef by  
439 improving the eating quality, including tenderness, and reducing cooking loss. The marinade  
440 which produced sous-vide beef with the best quality (the lowest WBSF and high scores for the  
441 juiciness, tenderness, meat taste acceptability and overall quality) was Old Polish. It was the

442 only marinade used in this study which contained only garlic and pepper and on the contrary to  
443 the remaining marinades did not contain red pepper. The simple spices turned out to work the  
444 best in sous-vide beef. The results of this study have a potential for a practical application in  
445 terms of providing consumers guidelines for beef preparation using marinating and sous-vide  
446 to obtain highly acceptable products. The described way of preparing the beef using marinating  
447 and sous-vide cooking, might be used to make dishes also for elderly people due to the fact that  
448 these treatments decrease an initial bite effort. Moreover, introducing marinated sous-vide beef  
449 as a ready-to-eat dish which would require only short heating before the consumption, would  
450 broaden the diversity of beef products in the market according to the assumption that the beef  
451 industry should ensure that the textural preferences of all population cohorts are provided for.  
452 Low cooking losses noted in this study in marinated sous-vide beef favourable affect the  
453 profitability of the production on the industrial scale.

454

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462

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