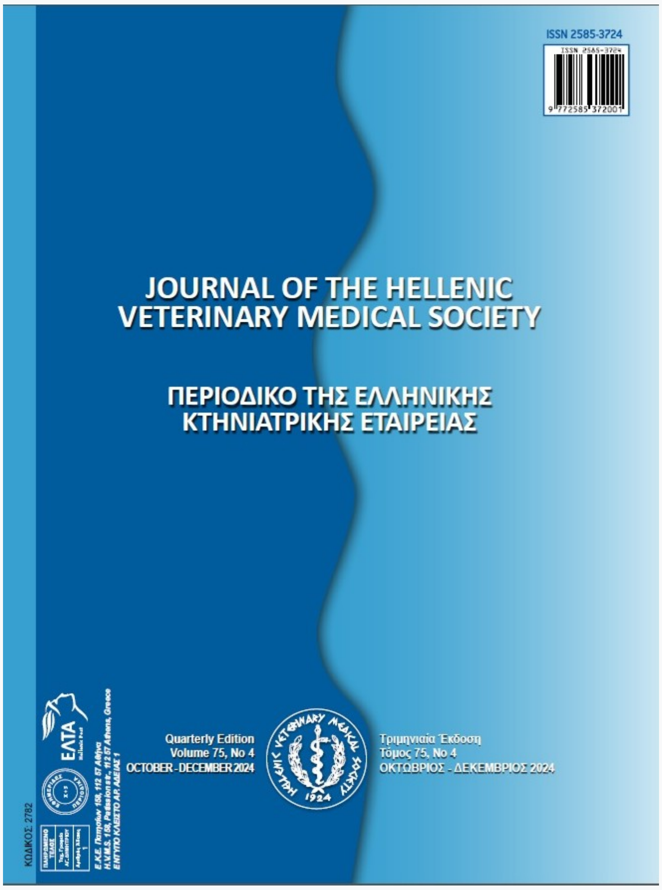
Journal of the Hellenic Veterinary Medical Society

Vol 75, No 4 (2024)



Yoghurt Acid Whey Marination - The Case of Lamb and Beef Meat

A Karageorgou, G Orfanou, I Petrou, M Goliomytis, G Theodorou, I Politis, P Simitzis

doi: [10.12681/jhvms.36955](https://doi.org/10.12681/jhvms.36955)

To cite this article:

Karageorgou, A., Orfanou, G., Petrou, I., Goliomytis, M., Theodorou, G., Politis, I., & Simitzis, P. (2025). Yoghurt Acid Whey Marination - The Case of Lamb and Beef Meat. *Journal of the Hellenic Veterinary Medical Society*, *75*(4), 8303–8312. https://doi.org/10.12681/jhvms.36955

J HELLENIC VET MED SOC 2024, 75 (4): 8303-8312
ΠΕΚΕ 2024, 75 (4): 8303-8312

Research article
Ερευνητικό άρθρο

Yoghurt Acid Whey Marination - The Case of Lamb and Beef Meat

A. Karageorgou[1], G. Orfanou[2], I. Petrou[3], M. Goliomytis[4], G. Theodorou[5], I. Politis[6], P. Simitzis[7]*

Laboratory of Animal Breeding and Husbandry, Department of Animal Science, Agricultural University of Athens, Athens, Greece

ABSTRACT: Yoghurt acid whey (YAW) is an effluent of yoghurt production and is related with enhanced risk of environmental pollution due to its great organic matter levels, which elicit an increased biological oxygen demand. During the previous decades a great effort has been exerted in finding sustainable applications of YAW. Therefore, YAW utilization in meat processing industry could be considered as a feasible option, since immersion of meat in marinades made of natural com-pounds is a process that is in constant advance due to its beneficial implications on meat organoleptic characteristics. In the present study, several quality traits and oxidation status of beef and sheep meat were evaluated after their marination into YAW. Forty samples for each meat type were assigned at random to one of five following treatments: CON, in the absence of marination; T1 and T3, where meat was immersed into YAW for 15 and 10 h at 4°C (pH of 4.5), respectively, or T2 and T4, where samples were treated as in the T1 and T3 group, respectively, while carvacrol was also incorporated at 0.5 g/L. As shown, meat shear force value was decreased as a result of YAW marination for 15 h in beef and sheep meat samples, while the other quality characteristics (pH, color, cooking loss) were not dramatically influenced. On the other hand, meat oxidative stability was also improved in both meat types. As it can be pointed out, beef and sheep meat soaking into YAW for 15 h improves tenderness, however this is not evident in case of 10 h of immersion. At the same time, oxidative stability was also improved as a consequence of YAW marination especially in beef meat and lower MDA values of lamb meat were observed in carvacrol supplemented groups.

***Keywords*:** yoghurt acid whey; lamb meat; beef meat; tenderness; color attributes; oxidative stability

Corresponding Author:
Panagiotis Simitzis, Laboratory of Animal Breeding and Husbandry, Department of Animal Science, Agricultural University of Athens, 75 Iera Odos, 11855, Athens, Greece
E-mail address: pansimitzis@aua.gr

Date of initial submission: 16-2-2024
Date of acceptance: 9-7-2024

INTRODUCTION

Yoghurt production is in a constant rise in Greece; 195,510 tn were produced in 2020 according to the most recent data of FAO (FAOSTAT, 2023). Greek strained yoghurt is appreciated worldwide as a highly nutritious dairy product with high protein content and as a result the production of similar products, known as Greek Yoghurt or Greek-style Yoghurt, is constantly increased (Karastamatis et al., 2022). As a consequence, a great quantity of yoghurt acid whey (YAW) is derived after milk acid coagulation through the addition of mineral or organic acids or the fermentation by lactobacilli posing a hazard to the environment (Ryan and Walsh, 2016). YAW is considered as a major pollutant due to its high biological oxygen demand (BOD) and organic matter (Rocha-Mendoza et al., 2020). As a result, dairy food industries have long striven to discover sustainable applications of YAW (Zotta et al., 2020). Since nowadays, it is usually utilized as a fertilizer that is mixed with manure before its application or is directly added to the soil (Ketterings et al., 2023). Acid whey is also used in livestock diets, after its mixing with silage (Erickson, 2023). At the same time, ingredients of YAW, such as lactose, could be further used for the generation of energy in wastewater bioreactors (Menchik et al., 2019; Guimarães et al., 2010).

As already pointed out, dairy food industries have sought to develop sustainable applications for YAW utilization that ensure its desired commercialization and valorization. Composition of YAW is influenced by several factors, such as the source of the milk, type of manufactured yogurt, milk thermal treatment, storage after milking, etc (Lucas et al., 2006). Even YAW collected from the same source under identical processing conditions can have different protein contents across seasons (Lievore et al., 2015). Moreover, the recent innovative processing technologies of whey contribute to the isolation of high-value whey fractions that are comprised of several bioactive compounds and characterized by exceptional antioxidant and antimicrobial properties (Chandrajith and Karunasena, 2018). These compounds could be utilized as flavor enhancers, binders or egg white replacers in a great variety of food products (Walzem et al., 2002). In meat industry, inclusion of acid whey in dry-cured pork loins (Stadnik and Stasiak, 2016) and sausages (Wójciak et al., 2014) improved oxidative stability without further side effects on their organoleptic and physicochemical traits. At the same time, several herbs, such as oregano, and their extracts have already been included to marinades aiming at the improvement of meat oxidation status and the prolongation of its shelf life (Van Haute et al., 2016; Gavriil et al., 2021). Carvacrol is a phenolic monoterpenoid contained in several plants of Labiatae family and is characterized by its intense antioxidant and antimicrobial properties (Skendi et al., 2017).

Several types of "convenience" meat products, such as the marinated ones, gain ground in the world market due to the sedentary way of living (Gómez et al., 2020). "Clean label" marinades made from natural compounds may beneficially modify the sensory attributes of the product and fortify consumer's health (Gök and Bor, 2016). In general, YAW contains low protein levels, while its content in lactic acid and calcium is high contributing to a lower pH value than that of the sweet whey derived from cheese (Rocha-Mendoza et al., 2020; Menchik et al., 2019). As a result, YAW is appeared as an ideal tenderizer agent, since soaking into acidic solutions has been routinely applied for meat softening and flavouring (Wenham and Locker, 1976).

Our preliminary results pointed out that meat immersion in YAW marinade for 20h could be suggested as an inventive approach for the improvement of rabbit, pork and sheep meat tenderness, whereas the other quality traits were not dramatically influenced (Simitzis et al., 2021). Moreover, pork meat immersion into YAW for 10- 15h can also be suggested as beneficial for meat softness with minimal changes in meat organoleptic characteristics (Karageorgou et al., 2023). Tenderness is a meat quality trait that the consumer strongly links to meat palatability and is therefore pivotal for its purchase.

Data concerning the influence of YAW marinades on sheep and beef meat quality characteristics are scarce. Consumers often use extrinsic cues such as color to decide which meat product to buy. On the other hand, tenderness is the most important factor affecting beef palatability and is strongly linked to consumer satisfaction (Garmyn, 2020). In our recent work (Simitzis et al., 2021), sheep meat was marinated into YAW for 20h and its organoleptic properties were assessed in raw and cooked samples on day 1. However, based on the aforementioned studies, the application of YAW as marinade could improve tenderness and delay lipid oxidation rates even after shorter periods of marination. As a result, the purpose of the current study is to highlight the beneficial influence of YAW marination for 10-15h on quality traits and oxidation status of sheep and beef meat after 1-9 days of refrigerated and 30-60 days of frozen storage

MATERIALS AND METHODS

Meat Samples and Marinades

Sheep and beef meat samples were dissected from 6-months-old lambs and 12-months-old calves, respectively, slaughtered in a commercial abattoir to guarantee identical rearing and slaughtering parameters and were transported to the laboratory on ice and stored at 4°C till analyses that were performed within 4 h. In brief, longissimus thoracis muscle between the 6th and 13th rib was collected for the determination of meat quality traits. Meat samples derived from eight lambs or calves and each sample was further divided into 5 sub-samples that were allocated at random to one of the following five groups: control (C), without soaking into YAW or one of the four experimental treatments (T), such as T1 and T3, where the samples were marinated into YAW for 15 and 10h at 4°C, respectively, or T2 and T4 that were as T1 and T3 with a simultaneous inclusion of carvacrol (Sigma-Aldrich, St. Louis, USA) at the level of 0.5g/L, a quantity selected based on our preliminary trials. Carvacrol is a phenolic monoterpenoid and is well known for its antioxidant activity (Skendi et al., 2017).

The yoghurt acid whey that was utilized in the current study originated from dairy cattle milk. YAW marinade was prepared by mixing approximately 10 g of YAW powder with 100 mL of distilled water to obtain a pH value of 4.5. YAW was a dry free-flowing powder mechanically produced from Greek-style strained yoghurt fermented with *Lactobacillus bulgaricus* and *Streptococcus thermophiles*, possessing a moisture and ash content of 4 and 11%, respectively. It also contained 72% lactose, 8.5% galactose, 6% lactic acid and 5% protein plus 18g Calcium, 14.4g Chloride, 1.7g Magnesium, 6g Phosphorus, 24.7g Potassium, 6.6g Sodium, 1.13mg Ferrum and 0.48mg Copper per kg (Epirus Protein S.A., Ioannina, Greece).

Meat Quality Evaluation

The exact weight of raw meat (60 ± 5 g) was recorded before and after their marination into YAW and the absorption of marinade was estimated as a proportion of the initial weight (%). Lamb and beef meat samples were then put in appropriate heat-resisting plastic bags and placed in a water bath at 75 °C for 35 min (Hopkins et al., 2010) and at 80°C for 30 min (Sikes and Tume, 2014), respectively, were then cooled by running water and then remained to equilibrate at room temperature. Meat samples were then weighed to determine cooking loss (%) that is a method of assessing water-holding capacity (Honikel, 1987). Shear force value was measured in samples with a cross section of 1 cm2 that were cut parallel to the muscle fibers by a Warner Bratzler (WB) shear blade fitted to a Zwick Testing Machine Model Z2.5/TN1S (Zwick GmbH & Co., Ulm, Germany) (in triplicate). Peak force values were calculated in Newton. Warner-Bratzler shear force value measurement is a typical procedure for the evaluation of meat tenderness (Novaković and Tomašević, 2017).

A portable pH meter (HI 99163 model, Hanna instruments, Romania) was used for the recording of acidity values in raw and cooked meat samples on day 1, but also till the 9th day after storage at 4°C. Standarization of the pH meter was carried out at room temperature by using buffers with pH values of 4.0 and 7.0 (Merck, Darmstadt, Germany). Color attributes (lightness - L, redness - a*, and yellowness - b*) were also measured in raw and cooked meat samples on day 1, but also 3, 6 and 9 days after storage at 4°C, by a Miniscan XE (HunterLab, Reston, VA, USA) chromameter that was standarized with the use of a white and black tile and assigned on the CIE-LAB system (Commission International de l' Eclairage, 1976).

Malondialdehyde (MDA) levels could serve as an indicator of lipid oxidation and were measured on day 1, but also 3, 6 and 9 days after storage at 4°C and 30 and 60 days after storage at -20°C by a selective third-order derivative (3D) spectrophotometric method (Botsoglou et al., 1994). In brief, 5 mL of butylated hydroxytoluene (BHT) in hexane (8 g/L) and 8 mL of aqueous trichloroacetic acid (TCA) (50 g/L) were mixed with 2 g from each raw or cooked meat sample (in duplicate) and were then homogenized (Unidrive x 1000, CAT, M. Zipperer GmbH, Ballrechten-Dottingen, Germany). The mixture was then centrifuged for 5 min at 5000x g and after hexane was discarded, 2.5 mL of the bottom layer was mixed with 1.5 mL of aqueous 2-thiobarbituric acid (TBA) (8 g/L). The obtained solution was further incubated at 70°C for 30 min. It was then stayed to cool under running water and equilibrate and was subjected to a 3D spectrophotometry (Hitachi U3010 Spectrophotometer) in the range of 500-550 nm. MDA content (ng/g wet tissue) was measured on the basis of the height of the third-order derivative peak at 521.5 nm, by comparing with the slope and intercept data of the standard calibration curve created by using the MDA pre-cursor 1,1,3,3-tetraethoxypropane (TEP).

Statistical Analysis

Data for marinade absorption, shear force value and cooking loss were assessed by using analysis of variance with marination treatment as a fixed effect. pH value, color at-tributes and MDA content were analysed by a mixed model procedure appropriate for repeated measurements per subject, with marination treatment as a fixed effect (five treatment groups; C, T1, T2, T3, T4 and T5) and storage duration as repeated factor. Results are displayed as least squares (LS) means ± standard error of mean (S.E.M.). Differences of means were detected at a 0.05 with Bonferroni adjustment; analyses were conducted with Sas/Stat (2011).

RESULTS

Lamb meat

No significant differences for the marinade absorption (%) in lamb meat were found among the treatment groups (Table 1). As also indicated in Table 1, lamb meat shear force values were decreased and as a result tenderness was ameliorated after yoghurt acid whey marination for 15h, but not for 10h ($P<0.001$). In contrast, cooking loss (%) was increased as a result of lamb meat soaking in T1 and T4 groups ($P<0.05$), but not in T2 and T3 groups (Table 1). Moreover, YAW marination resulted in a decline in pH values in raw but also cooked meat from day 1 till day 9 after storage at 4°C (Table 2; $P<0.05$).

An increase in lightness (L*) was observed in raw meat (day 0) marinated into yoghurt acid whey ($P<0.05$), apart from group T2, but this effect was not evident after cooking ($P>0.05$) (Fig. 1A). On the other hand, redness (a*) of raw meat samples marinated into YAW was decreased (day 0; $P<0.05$), whereas no other significant effects were indicated for cooked samples on days 1, 3, 6 and 9 ($P>0.05$) (Fig. 1B). Yellowness (b*) was not influenced by soaking into YAW (Fig. 1C; $P>0.05$). Nevertheless, YAW marinade significantly affected lamb meat oxidation rates, since MDA values declined on day 1 of refrigerated storage and on days 30 and 60 of frozen storage (Table 3; $P<0.01$). On the other hand, increased MDA values in T1 and T3 groups compared to the controls were observed on days 6 and 9 after storage at 4°C (Table 3; $P<0.05$). Addition of carvacrol in the yoghurt acid whey marinade further ameliorated lamb meat oxidation status, as indicated by the declined MDA values of the T2 and T4 compared to the T1 and T3 group, after 3 and 6 days of refrigerated storage and 30 and 60 days of frozen storage (Table 3; $P<0.05$).

Beef meat

No significant differences for the marinade absorption (%) of beef meat were found among the treatment groups (Table 1; $P>0.05$). As presented in Table 1, beef meat shear force values were decreased after 15h of YAW marination resulting in an improvement of meat tenderness ($P<0.05$); however, no effect of YAW marination for 10h on meat shear force value was illustrated. Cooking loss (%) showed increased values as an effect of beef meat immersion into YAW for 15h ($P<0.05$), but not for 10h (Table 1). On the other hand, meat pH values in raw and cooked samples dropped due to YAW marination on day 1 and 3 after storage at 4°C (Table 2; $P<0.05$). On day 6, pH values were lower in T3 and T4 compared to the other groups ($P<0.05$), whereas on day 9, T2 and T3 groups displayed the lowest pH values ($P<0.05$). Lightness

Table 1. Effects of YAW marination on meat marinade absorption (%), cooking loss (%) and shear force (N) (LS means ± s.e.m.)

	Control*	T1	T2	T3	T4	SEM	P-value
Lamb							
Marinade Absorption (%)	-	6.67	6.64	6.36	6.37	0.59	NS
Cooking Loss (%)	19.97^{a}	29.09^{b}	25.37^{ab}	24.95^{ab}	30.42^{b}	1.94	<0.05
Shear Force (N)	35.09^{a}	25.13^{b}	25.38^{b}	29.90^{ab}	29.76^{ab}	1.87	<0.001
Beef							
Marinade Absorption (%)	-	6.42	6.40	6.23	6.24	0.53	NS
Cooking Loss (%)	18.17^{a}	23.50^{b}	22.29^{b}	20.70^{ab}	20.27^{ab}	0.86	<0.05
Shear Force (N)	25.37^{a}	19.06^{b}	18.54^{b}	22.53^{ab}	23.36^{ab}	1.60	<0.05

*The treatment groups were: control, without immersion or one of the four soaking treatments, such as T1 and T3, where the samples were marinated into yoghurt acid whey for 15 and 10h at 4°C, respectively, or T2 and T4, in which the samples were treated as in T1 and T3, respectively, with a concomitant addition of carvacrol at the level of 0.5g/L.

[a, b] Values sharing dissimilar superscripts are significantly different.

(L*) values were higher in raw (day 0) meat samples that were immersed into YAW compared to the controls (P<0.05), and this effect remained in cooked samples (P>0.05) (Fig. 2A). In detail, T1, T3 and T4 groups had higher values for L* in comparison to the other groups on days 1, 3, 6 and 9 of refrigerated storage (P<0.05). Redness (a*) of raw (day 0) meat samples was decreased as an effect of yoghurt acid whey marination (P<0.05), while no significant differences were shown among groups on day 1, 3, 6 and 9 for cooked samples (P>0.05) (Fig. 2B). Meat yellowness (b*) was not influenced by the immersion into YAW (Fig. 2C; P>0.05). However, YAW marination significantly improved the oxidative stability of beef meat, since MDA values declined on day 1, 3, 6 and 9 at 4°C and on day 30 at -20°C (Table 3; P<0.01). Addition of carvacrol in YAW marinade did not influence beef meat oxidative stability, with the exception of day 30 at -20°C, when T2 and T4 had lower MDA values compared to the other groups (Table 3; P<0.05).

Table 2. Effects of YAW marination on meat pH (LS means ± s.e.m.)

	Control*	T1	T2	T3	T4	SEM	P-value
Lamb							
Raw	5.74[a]	5.52[b]	5.48[b]	5.47[b]	5.53[b]	0.02	<0.05
Cooked - day 1	5.95[a]	5.82[b]	5.80[b]	5.75[b]	5.72[b]	0.02	<0.05
Cooked - day 3	5.94[a]	5.70[b]	5.77[b]	5.77[b]	5.76[b]	0.02	<0.05
Cooked - day 6	6.22[a]	5.95[b]	5.97[b]	6.04[b]	6.04[b]	0.03	<0.05
Cooked - day 9	6.12[a]	5.74[b]	5.87[c]	5.94[c]	5.98[c]	0.03	<0.05
Beef							
Raw	5.66[a]	5.30[b]	5.34[b]	5.35[b]	5.28[b]	0.03	<0.05
Cooked - day 1	5.93[a]	5.72[b]	5.76[b]	5.67[c]	5.76[b]	0.02	<0.05
Cooked - day 3	5.93[a]	5.75[b]	5.80[b]	5.79[b]	5.80[b]	0.02	<0.05
Cooked - day 6	5.83[a]	5.84[a]	5.79[a]	5.71[b]	5.70[b]	0.02	<0.05
Cooked - day 9	5.80[a]	5.82[a]	5.73[b]	5.69[b]	5.80[a]	0.03	<0.05

*The treatment groups were: control, without immersion or one of the four soaking treatments, such as T1 and T3, where the samples were marinated into yoghurt acid whey for 15 and 10h at 4°C, respectively, or T2 and T4, in which the samples were treated as in T1 and T3, respectively, with a concomitant addition of carvacrol at the level of 0.5g/L.
[a, b, c] Values sharing dissimilar superscripts are significantly different.

Table 3. Effect of yoghurt acid whey marination on meat malondialdehyde - MDA (ng/g) values (LS means ± s.e.m.)

	Control*	T1	T2	T3	T4	SEM	P-value
Lamb							
Raw	17.35	10.58	8.72	16.51	10.47	1.30	NS
Cooked - day 1 stored at 4°C	127.55[b]	19.01[a]	16.98[a]	35.47[a]	20.06[a]	8.27	<0.001
Cooked - day 3 stored at 4°C	324.96[b]	266.01[ab]	188.69[a]	296.27[b]	187.1[a]	17.12	<0.05
Cooked - day 6 stored at 4°C	566.65[b]	675.01[a]	562.6[b]	641.24[ab]	576.13[b]	14.86	<0.05
Cooked - day 9 stored at 4°C	580.05[b]	679.75[a]	688.75[a]	692.99[a]	617.75[ab]	14.67	<0.05
Cooked - day 30 stored at -20°C	173.44[c]	127.14[a]	104.87[ab]	141.83[a]	67.17[b]	6.34	<0.05
Cooked - day 60 stored at -20°C	234.43[c]	146.03[ab]	118.6[a]	190.21[bc]	112.26[a]	13.55	<0.01
Beef							
Raw	34.78[c]	14.07[a]	12.26[a]	22.49[b]	19.5[ab]	2.65	<0.01
Cooked - day 1 stored at 4°C	85.74[b]	27.64[a]	27.22[a]	67.82[bc]	36.59[ac]	13.06	<0.05
Cooked - day 3 stored at 4°C	208.35[b]	148.99[a]	123.71[a]	152.57[a]	131.17[a]	12.68	<0.01
Cooked - day 6 stored at 4°C	295.29[a]	268.6[a]	230.11[b]	273.77[a]	236.43[b]	9.69	<0.05
Cooked - day 9 stored at 4°C	639.85[b]	404.23[a]	396.24[a]	570.06[ab]	545.03[ab]	69.17	<0.05
Cooked - day 30 stored at -20°C	181.94[cd]	140.81[a]	81.54[b]	153.04[ad]	103.05[b]	11.41	<0.05
Cooked - day 60 stored at -20°C	265.93	184.08	134.25	198.14	128.93	50.91	NS

*The treatment groups were: control, without immersion or one of the four soaking treatments, such as T1 and T3, where the samples were marinated into yoghurt acid whey for 15 and 10h at 4°C, respectively, or T2 and T4, in which the samples were treated as in T1 and T3, respectively, with a concomitant addition of carvacrol at the level of 0.5g/L.
[a, b, c,d] Values sharing dissimilar superscripts are significantly different.
NS: Not significant

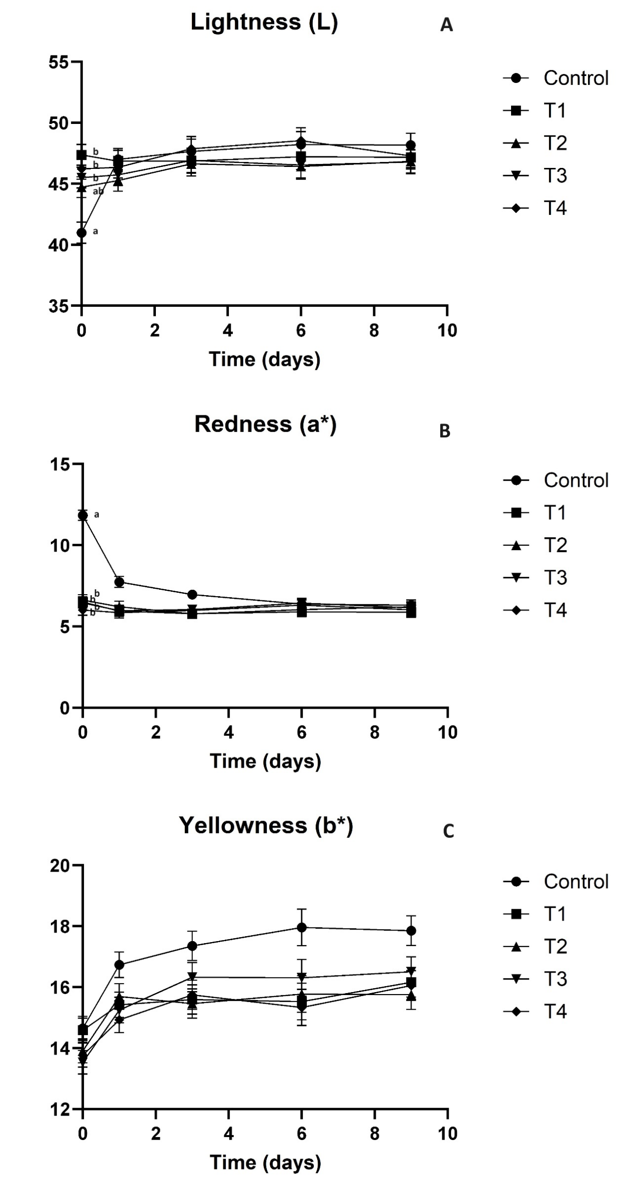


Figure 1. Effect of lamb meat immersion into yoghurt acid whey for 10-15h on the values of: (A) lightness - L, (B) redness - a*, (C) yellowness - b*. The treatment groups were: control, without immersion or one of the four soaking treatments, such as T1 and T3, where the samples were marinated into yoghurt acid whey for 15 and 10h at 4°C, respectively, or T2 and T4, in which the samples were treated as in T1 and T3, respectively, with a concomitant addition of carvacrol at the level of 0.5g/L. $^{a, b}$ Values sharing dissimilar superscripts are significantly different.

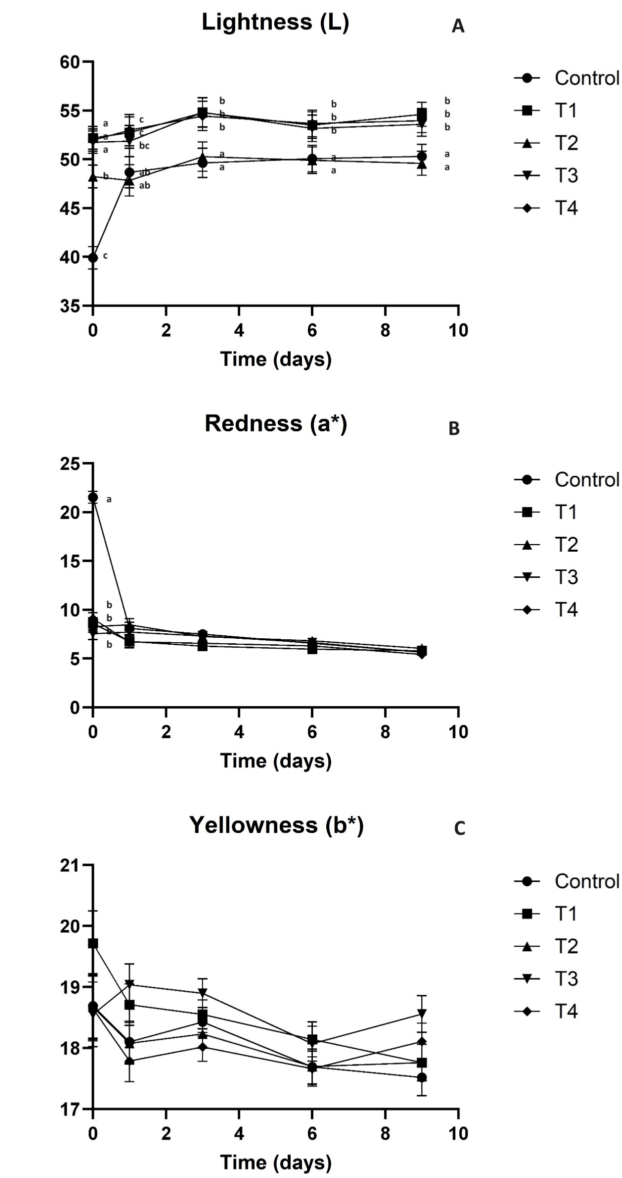


Figure 2. Effect of beef meat immersion into yoghurt acid whey for 10-15h on the values of: (A) lightness - L, (B) redness - a*, (C) yellowness - b*. The treatment groups were: control, without immersion or one of the four soaking treatments, such as T1 and T3, where the samples were marinated into yoghurt acid whey for 15 and 10h at 4°C, respectively, or T2 and T4, in which the samples were treated as in T1 and T3, respectively, with a concomitant addition of carvacrol at the level of 0.5g/L. $^{a, b}$ Values sharing dissimilar superscripts are significantly different.

DISCUSSION

Marination is one of the most well-known methods that improve meat flavor and softness. Immersion or soaking is a traditional technique for deriving marinated meat products, in which the ingredients of marinade penetrate through diffusion (Rao et al., 1989). As indicated in the present experiment, the increased concentration of calcium and lactic acid in acid whey resulted in reduced shear force values in both lamb and beef meat after YAW marination for 15h. In a previous study, immersion of lamb meat into food industry by-products containing acid whey for 24-48h ameliorated tenderness (Zavistanaviciute et al., 2023). In our recent work, in which lamb meat samples were soaked into YAW for 20h, shear force value was also decreased (Simitzis et al., 2021). In contrast, no influence on cutting force values were evident after immersion of beef into YAW marinade for 24 h (Wójciak et al., 2018), while beef tenderness was ameliorated after treated with lactic and citric acid solutions (Aktaş et al., 2003; Aktaş and Kaya, 2001) or calcium chloride and calcium lactate (Ostoja and Cierach, 2003).

A softening effect was also observed in pork meat marinated into YAW for 10-15h (Karageorgou et al., 2023) or in lactic acid solutions (1-3%) for 1-3 min (Grajales-Lagunes et al., 2012). Moreover, marination with YAW for 12 h (Augustyńska-Prejsnar et al., 2021) or lactic acid for 2 h (Ergezer and Gokce, 2011) decreased turkey meat shear force values. Decreased values for hardness, chewiness and shear force of hen breast meat were observed after its marination into acid whey and buttermilk for 24-48 h, highlighting an amelioration of tenderness (Augustyńska-Prejsnar et al., 2020). Similar results were reported after immersion of hen breast meat into sour milk and buttermilk for 12h at 4°C (Sokołowicz et al., 2021). Tenderness of chicken meat fillets was also positively influenced as an effect of soaking in whey for 12-24h (Vlahova-Vangelova et al., 2016) or 24 h (Augustyńska-Prejsnar et al., 2019a).

The general beneficial impact of acid marinades on meat tenderness could be attributed to the fact that the collagen connective tissue structure becomes less tight, since acids shatters its transversal bounds (Wójciak et al., 2015). As a result, acid-labile cross linkages in the collagen molecule are released resulting in a connective tissue breakdown and particularly perimysial tissue degradation (Wenham and Locker, 1976; Aktaş and Kaya, 2001).

YAW marination generally resulted in a decrease of lamb and beef meat pH values, as an effect of its acidity. A significant decline in pH values due the soaking into YAW for 10-20h has been already pointed out in our previous works (Simitzis et al., 2021; Karageorgou et al., 2023). Similar effects were reported after immersion of beef (Aktaş et al., 2003; Wójciak et al., 2015) and pork (Grajales-Lagunes et al., 2012) meat into acid whey. Acidic conditions, i.e. pH values within 5.2-5.5, are generally linked to ameliorated tenderness in beef muscle (Berge et al., 2001). Soaking into acid whey also reduced breast meat pH values in turkey (Ergezer and Gokce, 2011), chicken (Augustyńska-Prejsnar et al., 2019a) and pheasant (Augustyńska-Prejsnar et al., 2019b). The effects of marinades are often followed by swelling and prolonged extraction of myofibrillar proteins and linked to a reduction in pH values and an increment of ionic strength (Latoch et al., 2019; Goli et al., 2011).

Lightness was increased in raw lamb and beef meat samples marinated for 10-15h. In cooked samples, although this effect was also evident in beef stored at 4°C for 1-9 days, no differences were observed in lamb meat. These non-significant differences for lightness in cooked lamb meat samples were also found in our previous study, when meat remained in YAW for 20h (Simitzis et al., 2021).

Increase of lightness could be an effect of the enhanced quantity of extracellular water introduced into the meat through marinade that is scattered among the muscle fibers and influences meat reflectance properties. At the same time, pH reduction due to the proteolysis of myofibrillar and sarcoplasmic proteins by exogenous (originated from acid whey) and endogenous (calpains and cathepsins) peptidases may affect their water-binding properties (Aktaş and Kaya, 2001). On the other hand, redness (a*) showed reduced values in raw lamb and beef meat samples after immersion into YAW for 10-15h. In our previous experiment, redness was decreased in raw and cooked pork meat on day 1, while no effect was observed in chicken meat after soaking into YAW for 10-15h (Karageorgou et al., 2023). Augustyńska-Prejsnar et al. (2020) reached to similar conclusions with hen breast meat samples that were marinated in YAW for 24-48 h. Nevertheless, no significant effects on values of yellowness (b*) in lamb and beef meat samples were observed after YAW marination for 10-15h. A decline in redness and an increment in lightness were also pointed out in beef cuts immersed into a lactic acid aqueous mixture, whereas yellowness was not influenced (Aktaş and Kaya, 2001; Jimenez-Villarreal et al., 2003). In contrast to our findings, color attributes in uncured roast beef were not affected by YAW marination (Wójciak et al., 2018). However, an increase in a* and b* values was found after soaking of fermented beef eye round in acid whey (Wójciak et al., 2015).

Immersion of pork meat into a lactic acid solution did not induce a notable effect on its color parameters (Grajales-Lagunes et al., 2012). In contrast, a drop in yellowness of raw pork and chicken samples occurred after YAW marination for 10-20h (Simitzis et al., 2021; Karageorgou et al., 2023). Moreover, YAW marination was linked to an increment of lightness and yellowness in raw and roasted turkey meat samples, while redness was not affected (Augustyńska-Prejsnar et al., 2021). Immersion into buttermilk and whey for 24 and 48 h also increased lightness in hen breast meat samples (Augustyńska-Prejsnar et al., 2020). An increase in L value was also observed in raw pheasant breast muscles marinated into acid whey for 24h (Augustyńska-Prejsnar et al., 2019b).

YAW marination induces a general decline in MDA values in beef meat, however in sheep meat this effect was not evident after the first day, when MDA values were increased in YAW1 and YAW3 groups and carvacrol addition restored them at the levels of the controls. In general, whey proteins and peptides can be added to prevent lipid oxidation in meat products by acting as antioxidants (radical scavengers) or as barriers (coatings) to prevent exposure to oxygen and other conditions required for oxidation (Pihlanto, 2006; Ries et al., 2010; Singh et al., 2018). Wojciak et al. (2018) reported enhanced levels for 2-thiobarbituric acid reactive substances (TBARS) in beef marinated into acid whey after 1 and 28 days, but reduced TBARS content after 14 days of storage. On the other hand, soaking of fermented beef into acid whey also resulted in improved oxidative stability during storage (Wojciak et al., 2015). YAW marination of sheep meat for 20h with a concomitant addition of hesperidin decreased MDA values in raw and cooked samples on day 1 (Simitzis et al., 2021). Furthermore, oxidation stability was improved in chicken meat samples as an effect of YAW marination for 10-15h (Karageorgou et al., 2023). Inclusion of carvacrol into marinade had an additional beneficial effect on meat oxidative stability only in lamb meat, due its well-known activity as scavenger of free radicals (Al Jumayi et al., 2022). In general, marinades originated from dairy products improve the safety of meat products by attenuating the oxidation of fats and proteins and reducing the formation of heterocyclic aromatic amines and polycyclic aromatic hydrocarbons, possibly due to the biologically active substances and the competitive microflora derived from these products (Latoch et al., 2023a). The observed discrepancies could be possibly attributed to the different meat type and the fact that YAW already reduced lipid oxidation rates at such an extent in beef meat that carvacrol could not act synergistically. At the same time, after meat marination and cooking, protein degradation could take place, which can also negatively affect sensory quality of cooked meat and should be taken into account (Latoch et al., 2023b).

As already pointed out, YAW composition is affected by several factors and the results of the present study could be different if the YAW utilized was provided by another source. At the same time, evaluation of sensory attributes in cooked lamb and beef was not implemented, since our experiment was carried out during covid 19 outbreak and it was not possible to collect candidates to form the respective evaluation panel. At the same time, assessment of protein oxidation, determination of volatile compounds, implementation of texture profile analysis and examination of microbiological parameters could consolidate our knowledges on the effects of YAW marination on lamb and beef meat quality traits and they will be part of our future experimentations.

CONCLUSION

The results of the current study suggested that the marination of lamb and beef meat with yoghurt acid whey for 15h improved tenderness. At the same time, oxidative stability was greatly improved in beef meat samples as an effect of YAW marination, while in in lamb meat, MDA values were reduced on day 1, but they were increased afterwards as an effect of marination. Addition of carvacrol decreased MDA values to the levels of the control group or lower, indicating their great antioxidant potential in lamb meat. The utilization of YAW in lamb and beef meat sector can result in the minimization of hazards that are related with its dumping whereas an improvement of meat tenderness and oxidative stability in lamb and beef meat is evident without detrimental side effects on the other quality characteristics.

Funding Information

This research has been co- financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH - CREATE - INNOVATE (project code:T2EDK-00783)

Statement of Animal Rights

The methods used in the present experiment were approved by the Research Ethics Committee of the Department of Animal Science and Aquaculture of the Agricultural University of Athens under the guidelines of "Council Directive 86/609/EEC regarding the protection of animals used for experimental and other scientific purposes".

Data availability

The datasets generated during the current study are available from the corresponding author on reasonable request.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

REFERENCES

Aktaş, N., Aksu, M.I., Kaya, M., 2003. The effect of organic acid marination on tenderness, cooking loss and bound water content of beef. Journal of Muscle Foods, 14, 181-194. https://doi.org/10.1111/j.1745-4573.2003.tb00699.x

Aktaş, N., Kaya, M., 2001. The influence of marinating with weak organic acids and salts on the intramuscular connective tissue and sensory properties of beef. European Food Research and Technology, 21, 88-94. https://doi.org/10.1007/s002170100329

Al Jumayi, H.A., Allam, A.Y., El-Beltagy, A.E.-D., Algarni, E.H., Mahmoud S.F., El Halim Kandil, A.A., 2022. Bioactive Compound, Antioxidant, and Radical Scavenging Activity of Some Plant Aqueous Extracts for Enhancing Shelf Life of Cold-Stored Rabbit Meat. Antioxidants, 11, 1056. https://doi.org/10.3390/antiox11061056

Augustyńska-Prejsnar, A., Ormian, M., Kluz, M., Sokołowicz, Z., 2019a. Effect of using acid whey for marinating chicken breast muscles in organic production. Emirates Journal of Food and Agriculture, 31, 281-287. https://doi.org/10.9755/ejfa.2019.v31.i4.1940

Augustyńska-Prejsnar, A., Ormian, M., Hanus, P., Kluz, M., Sokołowicz, Z., Rudy, M., 2019b. Effects of marinating breast muscles of slaughter pheasants with acid whey, buttermilk, and lemon juice on quality parameters and product safety. Journal of Food Quality, 5313496. https://doi.org/10.1155/2019/5313496

Augustyńska-Prejsnar, A., Sokołowicz, Z., Hanus, P., Ormian, M., Kačániová, M., 2020. Quality and safety of marinating breast muscles of hens from organic farming after the laying period with buttermilk and whey. Animals, 10, 2393. https://doi.org/10.3390/ani10122393

Augustyńska-Prejsnar, A., Hanus, P., Sokołowicz, Z., Kačániová, M., 2021. Assessment of technological characteristics and microbiological quality of marinated turkey meat with the use of dairy products and lemon juice. Animal Bioscience, 34, 2003-2011. https://doi.org/10.5713/ab.21.0120

Berge, P., Ertbjerg, P., Larsen, L.M., Astruc, T., Vignon, X., Møller, A.J., 2001. Tenderization of beef by lactic acid injected at different times post mortem. Meat Science, 57, 347-357. https://doi.org/10.1016/S0309-1740(00)00110-8

Botsoglou, N.A., Fletouris, D.J., Papageorgiou, G.E., Vassilopoulos, V.N., Mantis, A.J., Trakatellis, A.G., 1994. A rapid, sensitive and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissues, food and feedstuff samples. Journal of Agricultural and Food Chemistry, 42, 1931-1937. https://doi.org/10.1021/jf00045a019

Chandrajith, V.G.G., Karunasena, G.A.D.V., 2018. Applications of whey as a valuable ingredient in food industry. Dairy and Veterinary Sciences, 6, 555698. https://doi.org/10.19080/JDVS.1018.06.555698

Ergezer, H., Gokce, R., 2011. Comparison of marinating with two different types of marinade on some quality and sensory characteristics of turkey breast meat. Journal of Animal Veterinary Advances, 10, 60-67. https://doi.org/10.3923/javaa.2011.60.67

Erickson, B. Acid whey: Is the waste product an untapped goldmine? Available online: https://cen.acs.org/articles/95/i6/Acid-whey-waste-product-untapped.html. Accessed on 23 9 2023.

FAOSTAT. Available online: http://www.fao.org/faostat/en/#data/QP. Accessed on 23 9 2023.

Garmyn, A. (2020). Consumer preferences and acceptance of meat products. Foods, 9(6), 708. https://doi.org/10.3390/foods9060708

Gavriil A., Zilelidou, E., Papadopoulos, A.E., Siderakou, D., Kasiotis, K.M., Haroutounian, S.A., Gardeli, C., Giannenas, I., Skandamis, P.N., 2021. Evaluation of antimicrobial activities of plant aqueous extracts against Salmonella Typhimurium and their application to improve safety of pork meat. Scientific Reports, 11, 21971. https://doi.org/10.1038/s41598-021-01251-0.

Gök, V., Y, Bor., 2016. Effect of marination with fruit and vegetable juice on the some quality characteristics of turkey breast meat. Brazilian Journal of Poultry Science, 18, 481-488. https://doi.org/10.1590/1806-9061-2016-0225

Goli, T., Bohuon, P., Ricci, J., Trystram G., Collignan, A., 2011. Mass transfer dynamics during the acidic margination of turkey meat. Journal of Food Engineering, 104, 161-168. https://doi.org/10.1016/j.jfoodeng.2010.12.010.

Gómez, I., Janardhanan, R., Ibañez, F.C., Beriain, M.J., 2020. The effects of processing and preservation technologies on meat quality: Sensory and nutritional aspects. Foods, 9, 1416. https://doi.org/10.3390/foods9101416

Grajales-Lagunes, A., Rivera-Bautista, C., Ruiz-Cabrera, M., Gonzalez-Garcia, R., Ramirez-Telles, J., Abud-Archila, M., 2012. Effect of lactic acid on the meat quality properties and the taste of pork Serratus ventralis muscle. Agricultural and Food Science, 21, 171-181. https://doi.org/10.23986/afsci.6082

Guimarães, P.M.R., Teixeira, J.A., Domingues, L., 2010. Fermentation of lactose to bio-ethanol by yeasts as part of integrated solutions for the valorisation of cheese whey. Biotechnology Advances, 28, 375-384. https://doi.org/10.1016/j.biotechadv.2010.02.002

Honikel, K.O., 1987. How to Measure the Water-Holding Capacity of Meat? Recommendation of Standardized Methods. In: Tarrant, P.V., Eikelenboom, G., Monin, G. (eds) Evaluation and Control of Meat Quality in Pigs. Current Topics in Veterinary Medicine and Animal Science, 38, pp 129-142. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-3301-9_11

Hopkins, D.L., Toohey, E.S., Warner, R.D., Kerr M.J., Van de Ven, R., 2010. Measuring the shear force of lamb meat cooked from frozen samples: Comparison of two laboratories. Animal Production Science, 50, 382-385, https://doi.org/10.1071/AN09162.

Jimenez-Villarreal, J.R., Pohlman, F.W., Johnson Z.B., Brown Jr, A.H., 2003. Lipid, instrumental color and sensory characteristics of ground beef produced using trisodium phosphate, cetylpypiridinium chloride, chlorine dioxide or lactic acid as multiple antimicrobial interventions. Meat Science, 65, 885-891. https://doi.org/10.1016/S0309-1740(02)00295-4.

Karageorgou, A., Paveli, A., Goliomytis, M., Theodorou, G., Politis I., Simitzis, P., 2023. The Effects of Yoghurt Acid Whey Marination on Quality Parameters of Pork and Chicken Meat. Foods, 12, 2360, https://doi.org/10.3390/foods12122360.

Karastamatis, S., Zoidou, E., Moatsou, G., Moschopoulou, E., 2022. Effect of modified manufacturing conditions on the composition of Greek strained yogurt and the quantity and composition of generated acid whey. Foods, 11(24), 3953. https://doi.org/10.3390/foods11243953

Ketterings, Q., Czymmek K., Cmi, S., Godwin, G., Ganoe, K. Guidelines for Land Application of Acid Whey. Available online: http://nmsp.cals.cornell.edu/publications/files/AcidWheyGuidelines2017.pdf Accessed on 23 9 2023.

Kumar, Y., Singh, P., Pandey, A., Tanwar, V.K., Kumar, R.R., 2017. Augmentation of meat quality attributes of spent hen breast muscle (Pectoralis Major) by marination with lemon juice vis-a-vis ginger extract. Journal of Animal Research, 7, 523-529. https://doi.org/10.5958/2277-940X.2017.00077.8

Latoch, A., Libera, J., Stasiak, D.M., 2019. Physicochemical properties of pork loin marinated in kefir, yoghurt or buttermilk and cooked sous vide. Acta Scientiarum Polonorum Technologia Alimentaria, 18, 163-

171. https://doi.org/10.17306/J.AFS.2019.0642.

Latoch, A., Czarniecka-Skubina E., Moczkowska-Wyrwisz, M., 2023a. Marinades Based on Natural Ingredients as a Way to Improve the Quality and Shelf Life of Meat: A Review. Foods, 12, 3638. https://doi.org/10.3390/foods12193638.

Latoch, A., Moczkowska-Wyrwisz, M., Sałek P., Czarniecka-Skubina, E., 2023b. Effect of marinating in dairy-fermented products and sous-vide cooking on the protein profile and sensory quality of pork longissimus muscle. Foods, 12, 3257. https://doi.org/10.3390/foods12173257.

Lievore, P., Simões, D.R., Silva, K.M., Drunkler, N.L., Barana, A. C., Nogueira, A., & Demiate, I.M., 2015. Chemical characterisation and application of acid whey in fermented milk. Journal of food science and technology, 52, 2083-2092. https://doi.org/10.1007/s13197-013-1244-z

Lucas, A., Rock, E., Chamba, J.F., Verdier-Metz, I., Brachet, P., Coulon, J.B., 2006. Respective effects of milk composition and the cheese-making process on cheese compositional variability in components of nutritional interest. Le Lait, 86(1), 21-41. https://doi.org/10.1051/lait:2005042

Menchik, P., Zuber, T., Zuber, A., Moraru, C.I., 2019. Composition of coproduct streams from dairy processing: Acid whey and milk permeate. Journal of Dairy Science, 102, 3978-3984. https://doi.org/10.3168/jds.2018-15951

Novaković, S., Tomašević, I., 2017. IOP Conf. Ser., 59th International Meat Industry Conference MEATCON2017 1-4 October 2017, Zlatibor, Serbia, Environmental Earth Sciences, 85012063. https://doi.org/10.1088/1755-1315/85/1/012063

Ostoja, H., Cierach, M., 2003. Effect of calcium ions on the solubility of muscular collagen and tenderness of beef meat. Nahrung, 47, 388-390. https://doi.org/10.1002/food.200390087

Pihlanto, A. (2006). Antioxidative peptides derived from milk proteins. International dairy journal, 16(11), 1306-1314. https://doi.org/10.1016/j.idairyj.2006.06.005

Rao, M.V., Gault, N.F.S., Kennedy, S., 1989. Variations in water-holding capacity due to changes in the fibre diameter, sarcomere length and connective tissue morphology of some beef muscles under acidic conditions below the ultimate pH. Meat Science, 26, 19-37. https://doi.org/10.1016/0309-1740(89)90054-5

Ries, D., Ye, A., Haisman, D., & Singh, H. (2010). Antioxidant properties of caseins and whey proteins in model oil-in-water emulsions. International Dairy Journal, 20(2), 72-78. https://doi.org/10.1016/j.idairyj.2009.09.001

Rocha-Mendoza, D., Kosmerl, E., Krentz, A., Zhang, L., Badiger, S., Miyagusuku-Cruzado, G., Mayta-Apaza, A., Giusti, M., Jimenez-Flores, R., García-Cano, I., 2020. Invited review: Acid whey trends and health benefits. Journal of Dairy Science, 104, 1262-1275. https://doi.org/10.3168/jds.2020-19038

Ryan, M.P., Walsh, G., 2016. The biotechnological potential of whey. Reviews in Environmental Science and Bio/Technology, 15, 479-498. https://doi.org/10.1007/s11157-016-9402-1

Sas/Stat, 2011. Statistical Analysis Systems, Version 9.3; SAS Institute Inc.: Cary, NC, USA.

Sikes A.L., Tume R.K., 2014. Effect of processing temperature on tenderness, colour and yield of beef steaks subjected to high-hydrostatic pressure. Meat Science, 97, 244-248. https://doi.org/10.1016/j.meatsci.2013.12.007.

Simitzis, P., Zikou, F., Progoulakis, D., Theodorou, G., Politis, I., 2021. A Note on the Effects of Yoghurt Acid Whey Marina-tion on the Tenderness and Oxidative Stability of Different Meat Types. Foods, 10, 2557. https://doi.org/10.3390/foods10112557

Singh, P., Singh, T. P., Gandhi, N., 2018. Prevention of lipid oxidation in muscle foods by milk proteins and peptides: A review. Food reviews international, 34(3), 226-247. https://doi.org/10.1080/87559129.2016.1261297

Skendi, A., Irakli, M., Chatzopoulou P., 2017. Analysis of phenolic compounds in Greek plants of Lamiaceae family by HPLC. Journal of Applied Research on Medicinal and Aromatic Plants, 6, 62-69. https://doi.org/10.1016/j.jarmap.2017.02.001.

Sokołowicz, Z., Augustyńska-Prejsnar, A., Krawczyk, J., Kačániová, M., Kluz, M., Hanus, P., Topczewska, J., 2021. Technological and sensory quality and microbiological safety of RIR chicken breast meat marinated with fermented milk products. Animals, 11, 3282. https://doi.org/10.3390/ani11113282

Stadnik, J., Stasiak, D.M., 2016. Effect of acid whey on physicochemical characteristics of dry-cured organic pork loins without nitrite. International Journal of Food Science and Technology, 51, 970-977. https://doi.org/10.1111/ijfs.13045

Van Haute, S, Raes, K., Van Der Meeren P., Sampers I., 2016. The effect of cinnamon, oregano and thyme essential oils in marinade on the microbial shelf life of fish and meat products. Food Control, 68, 30-39. https://doi.org/10.1016/j.foodcont.2016.03.025.

Vlahova-Vangelova, D.B., Balev, D.K., Dragoev, S.G., Kirisheva, G.D., 2016. Improvement of technological and sensory properties of meat by whey marinating. Scientific Works of University of Food Technologies, 63, 7-13.

Walzem, R.L., Dillard, C.J., German, J.B., 2002. Whey Components: Millennia of Evolution Create Funcionalities for Mammalian Nutrition: What we know and what we may be overlooking. Critical Reviews in Food Science and Nutrition, 42, 353-375. https://doi.org/10.1080/10408690290825574

Wenham, L.M., Locker, R.H., 1976. The Effect of Marinading on Beef. Journal of the Science of Food and Agriculture, 27, 1079-1084. https://doi.org/10.1002/jsfa.2740271202

Wójciak, K.M., Karwowska, M., Dolatowski, Z.J., 2014. Use of acid whey and mustard seed to replace nitrites during cooked sausage production. Meat Science, 96, 750-756.
https://doi.org/10.1016/j.meatsci.2013.09.002

Wójciak, K.M., Krajmas, P., Solska, E., Dolatowski, Z.J., 2015. Application of acid whey and set milk to marinate beef with reference to quality parameters and product safety. Acta Scientiarum Polonorum Technologia Alimentaria, 14, 293-302. https://doi.org/10.17306/J.AFS.2015.4.30

Wójciak, K.M., Kęska, P., Okoń, A., Solska, E., Libera, J., Dolatowski, Z.J., 2018. The influence of acid whey on the antioxidant peptides generated to reduce oxidation and improve colour stability in uncured roast beef. Journal of the Science of Food and Agriculture, 98, 3728-3734. https://doi.org/10.1002/jsfa.8883

Zavistanaviciute, P., Klementaviciute, J., Klupsaite, D., Zokaityte, E., Ruzauskas, M., Buckiuniene, V., Viskelis, P., Bartkiene, E., 2023. Effects of Marinades Prepared from Food Industry By-Products on Quality and Biosafety Parameters of Lamb Meat. Foods, 12, 1391. https://doi.org/10.3390/foods12071391

Zotta, T., Solieri, L., Iacumin, L., Picozzi, C., Gullo. M., 2020. Valorization of cheese whey using microbial fermentations. Applied Microbiology and Biotechnology, 104, 2749-2764. https://doi.org/10.1007/s00253-020-10408-2