Bulgarian Chemical Communications, Volume 55, Issue 4 (pp. 418-423) 2023 DOI: 10.34049/bcc.55.4.5556

Thermal stability of vegetable oil emulsions and influence on the texture parameters of cooked sausages

M. Momchilova[1*], G. Zsivanovits[1], M. Marudova[2]

[1]*Department of Food Technologies, Institute of Food Preservation and Quality, Agricultural Academy, 154 Vasil Aprilov Blvd., 4000 Plovdiv, Bulgaria*

[2]*Department of Physics, Faculty of Physics and Technology, Paisii Hilendarski University of Plovdiv, 24 Tsar Asen Street, 4000 Plovdiv, Bulgaria*

Received: February 15, 2023; Revised: August 07, 2023

This study is focused on the possibility of using two vegetable oil emulsions as substitutes for pork back fat in the traditional formulation of cooked sausages. The effect of these emulsions on the texture parameters of cooked sausages was investigated. The statistically significant difference ($P<0.05$) found in the texture parameters of the sausage samples was closely related to the solid fat index (SFI) which is a measure of the percentage of fat in crystalline (solid) phase to total fat (the remainder being in liquid phase) across a temperature gradient. The addition of vegetable oil emulsions reduced the solid fat index at temperatures above 0°C, which was the result of the animal fat substitution and lower melting temperature of the final product. The reduced crystalline phase content in the fats led to lower hardness, chewiness and gumminess values of the final products.

Keywords: Meat sausages, fat replacer, vegetable oil emulsions, DSC, texture

INTRODUCTION

Cooked sausages are widely distributed in a lot of countries and play a major role in the meat industry from an economic point of view. They can be made from different meat types, such as beef, pork, poultry, etc., with the addition of various flavours, fillers and binding agents. This type of sausages, however, is characterised by a high fat content, and the attempts at fat reduction aim to assist consumers in their efforts to limit the intake of large amounts of fats, including saturated fatty acids and cholesterol [1]. The excessive consumption of the latter is involved in the development of hypertension, obesity, cardiovascular and chronic diseases [2-4]. Fats, however, are an important factor that affects the emulsion stability and the water retention and emulsifying capacity of the meat batter [5], and these factors are directly responsible for the physical properties of meat products and their sensory perception by consumers [6-8]. The fat that is most commonly used in the manufacture of meat products, including cooked sausages, is pork back fat. The development of low-fat meat products without any changes in their technological and quality characteristics poses a challenge to the meat industry. Therefore, in recent years there has been growing interest in vegetable oils and the possibility of using them in meat product manufacture. In this regard chia and grape seed oils can be used in the production of cooked sausages because they contain ω-3 and ω-6 fatty acids [9], phytosterols, tocopherols, flavonoids, phenolic acids [10]. In this way they influence plasma cholesterol values with their cardioprotective and antidiabetic effects [11,12]. Compared to animal fats, vegetable oils contain larger amounts of unsaturated fatty acids and meet a number of dietary requirements [13]. This is one of the main reasons for the rising trend towards using vegetable oils in various food products, meat products in particular. Regardless of the positive effects of vegetable oils, each oil has different technological properties and depends largely on the characteristics of the raw material it is obtained from. The differences in melting and crystallisation points, the fatty acid composition, color, taste, liquid state, and the high unsaturated fatty acid content could have an adverse effect on a number of technological characteristics, e.g. the texture parameters of the meat products in which they are used [14-18]. In this aspect, pre-emulsification with a non-meat protein such as sodium caseinate is a promising approach to the manufacture of meat products by stabilising the meat batter so that the fat would not separate from the meat matrix [19] since this would affect the technological properties of meat products [20].

The aim of this study was to investigate the thermal characteristics of two types of emulsified oils as pork back fat substitutes and their effect on the texture parameters of reformulated cooked sausages.

* To whom all correspondence should be sent:
E-mail: masha821982@abv.bg

© 2023 Bulgarian Academy of Sciences, Union of Chemists in Bulgaria

MATERIALS AND METHODS

For the purposes of the experiment, we made seven test formulations with different amounts of pork back fat and the type and amount of vegetable oil emulsions are specified in Table 1. In order to preserve the texture of sausages as much as possible, an alternative approach has been proposed, including the replacement of animal fat with pre-emulsified vegetable oils [21] and the inclusion of a non-meat protein source to stabilize the meat emulsion system [22, 23]. The meat raw materials were purchased from stores, the potato starch "Stärkina" and sodium caseinate from the company Picco - Bulgaria, and the vegetable oils from specialized health food stores. The ingredients for the formulation of the emulsions were vegetable oils, sodium caseinate and water in a 5:1:5 ratio. The vegetable oil emulsions, sodium caseinate and hot water (60°C) (in a 5:1:5 ratio) were prepared on a cutter (model CL/5, FIMAR, Italy) in advance, one day before they were used. The sodium caseinate and the hot water were stirred for 2 min, then the oils were added and the mixture was chopped for another 3 min. The emulsion was cooled to 6-8°C. The experimental sausages were made by grinding the pork meat and back fat in a meat grinder through a 4 mm grinder plate; then, the meat was placed in the cutter working at a slow speed and sodium chloride, nitrite, polyphosphate and half of the ice were added. The emulsion was chopped at a high speed and after the water was absorbed, the sodium caseinate, spices and the rest of the ice were added. The chopping continued until a temperature of 6-8 °C was reached; then, the fat and/or emulsions were added. The chopping continued until 12 °C and finally, the starch was added. The chopping went on until 14 °C. The finished filling mass was transferred to a stuffer and stuffed into 50-mm polyamide casings, the individual pieces weighing 0.250 kg each. Heat processing was performed at 65 °C until 45 °C were reached at the centre of the sausage; then, the cooking continued at 78 °C until 72 °C were reached at the centre of the sausage, and held for 5 min. After cooling, the sausages were kept in a cold store at 4 ± 2 °C until the time of the analyses. The technological steps in the manufacture of the experimental samples are presented in Fig. 1. For the analysis of the texture profile of the finished sausages from sample P1 to sample P7 [19], a TA-XT Plus (Stable Micro Systems, Surrey, GB) texture analyser was used. The cylinder was 25 mm in diameter. Discs 60 mm in diameter and 19±2 mm in height were made from the sausage samples for the test. The samples were compressed at a rate of 2 mm s^{-1} to 5 mm deformation. The relaxation time between two compressions was set at 5 s. The hardness, springiness, homogeneity, chewiness, resilience, gumminess and adhesiveness were calculated for further analysis [24-26]. The melting profiles of the fats extracted from the investigated sausage samples from P1 to P7, as well as from GVO sample P8, GSO sample P9 and sample P10 PBF, were examined using a DSC 204F1 Phoenix differential scanning calorimeter (Netzsch Gerätebau GmbH, Germany). The instrument was calibrated with indium standard (T_m = 156.6 °C, ΔH_m = 28.5 $J.g^{-1}$). The sample was hermetically sealed in an aluminium pan. An empty, hermetically sealed aluminium pan identical to the sample pan was used as a reference. The experimental conditions were identical for all the products. The samples were heated at a heating rate of 5 °C/min to 80 °C and held for 30 min to ensure that the fat was fully melted and all the nuclei were destroyed [27]. After melting, the samples were cooled to -60 °C at a cooling rate of 5 $°C.min^{-1}$. The samples were stored at -60 °C for 30 min and finally, the melting curves were recorded by scanning the samples to 80 °C at a heating rate of 5.0 $°C.min^{-1}$. The solid fat index (SFI) was calculated as the percentage of fat in crystalline (solid) phase to total fat (the remainder being in liquid phase) across a temperature gradient.

All the data obtained were statistically analysed by one-way analysis of variance (ANOVA) using the Statgraphics 16 software product. Significant ($P < 0.05$) differences between the treatments were determined using Duncan's post hoc test. The experiments were made with fivefold repetitions, and the data in the graphs are the arithmetic means of the indicators measured. Statistically significant differences between the mean values were found at a probability less than 0.05. The interrelationships between the solid fat index (SFI) and the texture parameters were investigated by correlation analysis.

RESULTS AND DISCUSSION

The differences in the texture parameters of the reformulated sausages are presented in Table 2. The table shows that the use of emulsions of different oil types as animal fat substitutes had a considerable effect on all textural properties except for the resilience parameter, and there was a minor difference in the homogeneity parameter. As had been expected, the emulsions of the two vegetable oil types used as pork back fat substitutes and their quantity affected the hardness ($P<0.05$). The use of the emulsions resulted in a softer texture compared to the control sample, with the exception of sample P4 ($P<0.05$).

Table 1. Sample formulations of cooked meat sausages with vegetable oil emulsions

Ingredients, g.kg^{-1}	Samples						
	Sample P1 (control)	Sample P2	Sample P3	Sample P4	Sample P5	Sample P6	Sample P7
Pork meat	790	790	790	790	790	790	790
Pork back fat	210	-	-	105	105	-	70
Emulsion (chia oil + water + sodium caseinate)	-	210	-	105	-	105	70
Emulsion (grape seed oil + water + sodium caseinate)	-	-	210	-	105	105	70
Salt	20	20	20	20	20	20	20
Sodium nitrite	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Black pepper	4	4	4	4	4	4	4
Nutmeg	1	1	1	1	1	1	1
Sugar	2	2	2	2	2	2	2
Phosphates	2	2	2	2	2	2	2
Potato starch	30	30	30	30	30	30	30
Sodium caseinate	10	10	10	10	10	10	10
Water/ice	290	290	290	290	290	290	290

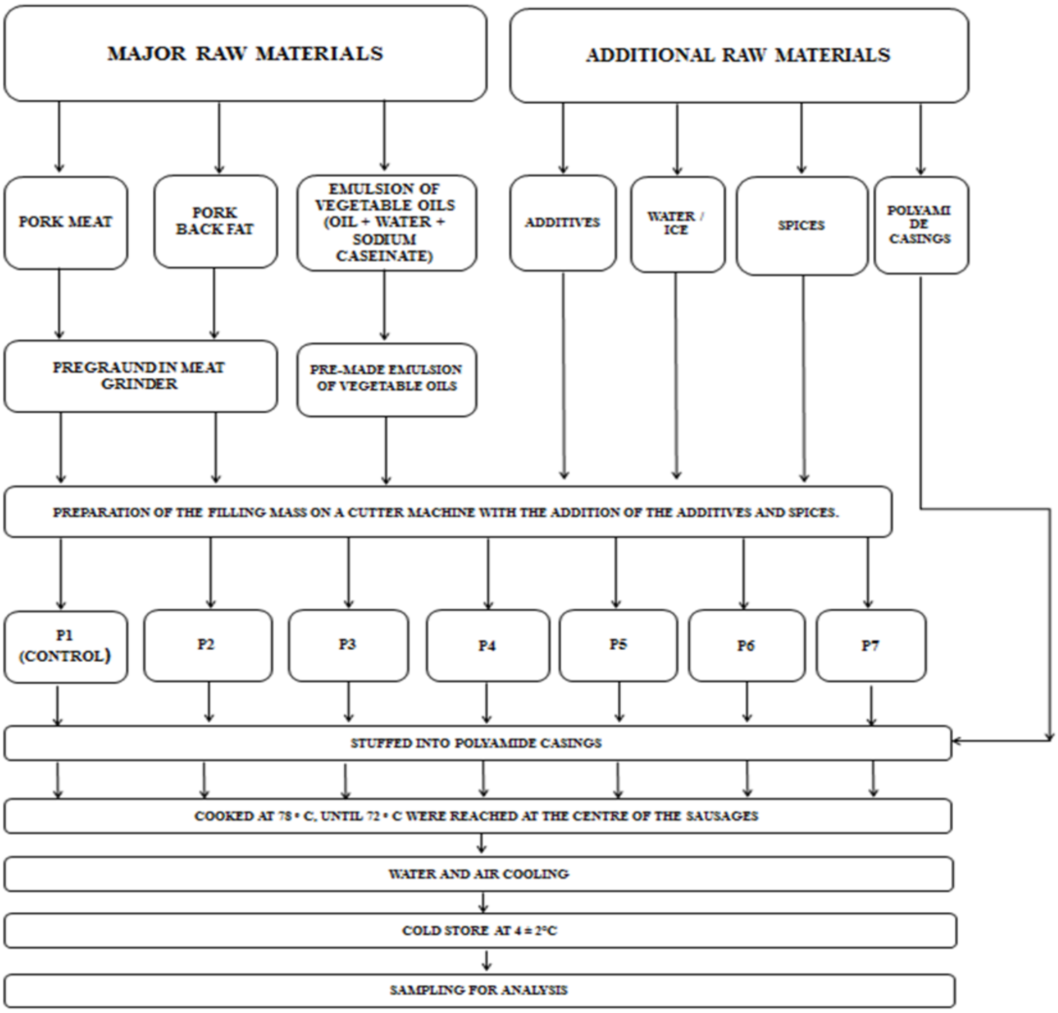

Fig. 1. Processing diagram of cooked sausages

Some authors [28] pointed out that the use of chia vegetable oil in reformulated sausages led to a rise in some of the texture parameters during storage. Other authors [29] reported that the use of vegetable oils as pork back fat substitutes in meat pâtés resulted in lower hardness values, perhaps due to the increased unsaturated fatty acid content in the vegetable oils. Based on previously published data about the fatty acid content of here investigated products [30], it could be concluded that the hardness values in our experiments were fully consistent with the above reports, and the value of sample P3, where 100 % of the animal fat had been replaced by grape seed oil emulsion, was the closest to and a little higher than that of the control sample. The lowest hardness value, statistically discernible ($P<0.05$) from the other samples, was measured for sample P6, where emulsions of both vegetable oils had been used. According to [31, 32], chewiness is a parameter that reflects the results connected with hardness since it is a secondary parameter dependent on hardness, and it provides information on the force or work needed for chewing the sample studied [25].

The studies demonstrated that the consumption of sample P4 was related to the greatest force needed for chewing, followed by sample P1. Resilience and gumminess provide information on the structural and mechanical properties of the tested products that affect their performance during consumption. The values measured in the reformulated sausages were closely related to the hardness and homogeneity values. The gumminess parameter showed higher values in sample P4, followed by the control sample, and they were statistically different ($P<0.05$) both from each other and from the other samples. As regards the springiness parameter, the use of chia and grape seed vegetable oils in emulsion form led to higher values in the experimental samples compared to the control sample ($P<0.05$), which could be attributed to the use of a non-meat protein as emulsifier, which, according to [33], improves the structural properties, jellifying capacity and springiness in the meat system. Adhesiveness expresses the degree of adhesion of the product to the working organ, i.e., the teeth, in its movement to the original position on completion of the first cycle. In view of the considerable differences in the adhesiveness (stickiness) of a product observed in the different samples, the effect of the two vegetable oil emulsions, from chia and grape seeds, needs to be taken into account. The adhesiveness of the experimental samples was found to decrease with the exception of sample P6, where emulsions of both vegetable oils had been used as pork back fat substitutes, all samples being statistically discernible ($P<0.05$) from the control sample.

One of the main thermal characteristics of lipids is the Solid Fat Index (SFI), which shows the part of the fat that is still in crystalline state at a curtain temperature. SFI is responsible for many of the fundamental characteristics of fatty foods, such as physical appearance, organoleptic properties and spreadability, also influencing the plasticity of an edible oil product [34]. The SFIs for the oil raw material (chia vegetable oil, grape seed oil and pork back fat) and for the sausages investigated are presented in Fig. 2. The SFI decreased most rapidly in the grape seed oil, and it was practically zero at temperatures above 0 °C. Its behavior was similar in the chia vegetable oil: it was higher at negative temperatures and dropped at positive temperatures. In comparison, the SFI in the pork back fat was the highest at positive temperatures. The SFI temperature dependence is strongly influenced by the fatty acid composition of fats, being lower for unsaturated fatty acids, which melt at negative temperatures.

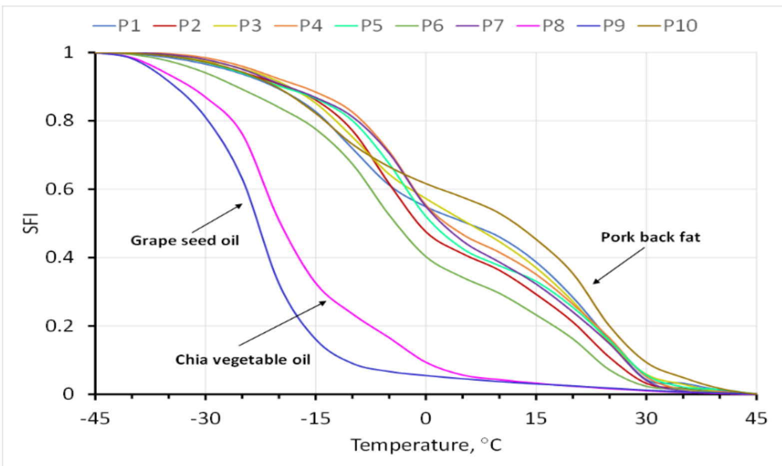

Fig. 2. SFI of the raw materials and sausages

Table 2. SFI of cooked sausage samples at 15 °C, texture parameters, and correlations between the SFI and the texture parameters

Sample	SFI (15°C)	Hardness (N)	Springiness	Homogeneity	Chewiness (N)	Resilience	Gumminess	Adhesiveness (Nmm)
P1	0.3870	24.23±2.39^{d}	0.91±0.03^{a}	0.57±0.03^{b}	12.48±1.19^{d}	0.45±0.02^{a}	13.73±1.29^{d}	-0.31±0.06^{b}
P2	0.2925	20.43±2.29^{b}	0.96±0.02^{c}	0.58±0.04^{b}	11.34±1b^{cd}	0.46±0.02^{a}	11.82±0.95^{b}	-0.14±0.03^{d}
P3	0.3702	22.84±2.7^{cd}	0.92±0.04^{ab}	0.58±0.05^{b}	12.13±2.08^{cd}	0.46±0.06^{a}	13.21±1.94^{cd}	-0.12±0.02^{d}
P4	0.3509	28.75±4.37^{e}	0.93±0.01^{ab}	0.53±0.03^{a}	14.01±2.07^{e}	0.44±0.04^{a}	15.1±2.18^{e}	-0.16±0.03^{d}
P5	0.3302	20.59±3.58^{b}	0.92±0.04^{ab}	0.55±0.03^{ab}	10.53±2.05^{ab}	0.46±0.04^{a}	11.4±2.21^{ab}	-0.27±0.05^{c}
P6	0.2322	18.21±1.32^{a}	0.92±0.04^{ab}	0.56±0.03^{b}	9.38±0.98^{a}	0.45±0.03^{a}	10.24±0.92^{a}	-0.38±0.07^{a}
P7	0.3225	21.1±2.56^{bc}	0.93±0.03^{bc}	0.57±0.04^{b}	11.28±1.47^{bc}	0.47±0.04^{a}	12.09±0.63^{bc}	-0.09±0.02^{e}
R*		0.6981	-0.3517	-0.0018	0.7601	-0.0622	0.7968	0.3516
P**		0.0811	0.4391	0.9970	0.0473	0.8943	0.0319	0.4395

$^{a-e}$-values within the same column bearing a common superscript did not differ statistically (P > 0.05)
R*- correlation between the texture parameters and SFI
P**- uncertainty level of the correlations

The lowest values of the index across the whole temperature range for the sausages studied were observed for sample P6, which contained the vegetable oils emulsions in equal proportions, with no pork back fat added. However, the values were higher than those of the vegetable oils used since the sample contained pork and, respectively, the animal fat included in it. The same sample showed the lowest hardness, chewiness and gumminess values, but also the highest adhesiveness values. The highest SFI was detected for the control sausage (P1), which contained pork back fat only. It ranked second with regard to the texture parameters. The full replacement of the pork back fat with chia oil emulsion (P2) resulted in very soft texture and a low SFI (15°C). The replacement of the pork back fat with GSO emulsion (P3) led to a high SFI (15°C) and moderate texture parameters. The hardest sausage (P4: pork back fat + chia oil emulsion) had a moderate SFI (15°C). The mixing of pork back fat with chia emulsion (P5) reduced the SFI (15°C) and the texture parameters. The equilibrium mixture (P7) of the fat components showed a high SFI (15°C) with moderate texture parameters and very low adhesiveness. It was interesting to note that the sausages prepared with fat mixtures (sample P4, P5 and P6) were characterised by lower SFIs than the pure fats. A possible reason could be the different morphology of the crystalline phase in the fat blends. In mixtures of materials that cannot co-crystallise, a more defective fine crystalline structure usually occurs, which is characterised by a lower melting point; hence, the SFI decreases [35]. In order to look for the interrelationships between the SFI at 15°C (Table 2) and the texture parameters, a correlation analysis was performed. It showed strong correlations with a meaningful uncertainty level between SFI: hardness (R=0.6981, P=0.0811), SFI: chewiness (R=0.7601, P=0.0473) and SFI: gumminess (R=0.7968, P=0.0319) (Table 2).

The SFI decrease led to a decrease in the hardness, chewiness and gumminess rheological parameters. Very similar results were reported by Dreher *et al*. [36, 37], who investigated the texture, appearance and sensory characteristics of plant-based salami analogues. He explained the observed correlations with the structure of the different fat particles, which affected the salami texture. [38] associated the change in texture with the degree of fatty acid saturation and the lower melting point of unsaturated fatty acids inherent to vegetable fats.

CONCLUSION

The use of vegetable oils in emulsion form as animal fat substitutes and their quantity in cooked sausages affected the texture parameters of the sausages. Sample P4, which contained equal amounts of chia vegetable oil emulsion and pork back fat, was characterised by the largest increase in the texture parameter values, except for homogeneity and resilience, compared to the control sample and the rest of the experimental samples. The lowest and statistically discernible values (P<0.05) for the control sample and the other samples were those for sample P6. The differences in the texture parameters were closely related to the decrease in the concentration of the fraction of fats in crystalline phase as indicated by the lower solid fat index (SFI).

Acknowledgements: *This study was funded by the Scientific Research Fund, the competition for fundamental scientific research of young scientists and post-doctoral students 2020, under project KP-06 M47/4 of 27 November 2020 "Vegetable oils and/or flours as new substitutes for animal fats,*

wholesome bioactive sources for the reformulation of emulsified meat sausages. Effects on the lipid profile, quality characteristics and technological properties",

REFERENCES

1. C. V. B. Souza, E. R. B. Bellucci, J. M. Lorenzo, A. C. D. S. Barretto, *Food Sci. Technol.,* **39**, 295 (2019).
2. M. A. D. Nobile, A. Conte, A. L. Incoronato, O. Panza, A. Sevi, R. Marino, *Meat Sci.*, **81**, 263 (2009).
3. Y. C. Trevisan, C. V. Bis, J. M. Henck, A. C. S. Barretto, *Braz. J. Food Technol.,* **19** (2016).
4. M. S. Rahman, J. K. Seo, M. A. Zahid, J. Y. Park, S. G. Choi, H. S. Yang, *Meat Sci*., **151**, 89 (2019).
5. Y. S. Choi, J. H. Choi, D.J. Han, H. Y. Kim, M. A. Lee, J. Y. Jeong, H. J. Chung, C. J. Kim, *Meat Sci*., **84**, 557 (2010).
6. D. Álvarez, M. Castillo, F. A. Payne, M. D. Garrido, S. Bañón, Y. L. Xiong, *J, Food Eng*., **82**, 310 (2007)
7. Y.S. Choi, J. H. Choi, D. J. Han, H. Y. Kim, M. A. Lee, H.W. Kim, J. Y. Jeong, C. J. Kim, *Meat Sci*., **82**, 266 (2009).
8. J. S. Lee, H. G. Kim, M. J. Choi, Y. J. Cho, *Food Sci. Anim. Resour.,* **40**, 262 (2020).
9. C. F. Rodrigues, W. Salgueiro, M. Bianchini, J. C. Veit, R. L. Puntel, T. Emanuelli, C. C. Dernadin, D. S. Ávila, *Nutr. Metab*., **15**, 1 (2018).
10. F. B. Shinagawa, F. C. D. Santana, L. R. O. Torres, and J. Mancini-Filho, *Food Sci. Technol*., **35**, 399 (2015).
11. Y. S. Choi, J. H. Choi, D. J. Han, H. Y Kim, M. A Lee, H. W. Kim, J. W. Lee, H. J. Chung, C. J. Kim, *Meat Sci*., **84**, 212 (2010).
12. E. Antonini, L. Torri, M. Piochi, G. Cabrino, M. A. Meli, R. D. Bellis, *Meat Sci*., **161**, (2020).
13. W. M. Willis, R. W. Lencki, A. G. Marangoni, *Crit. Rev. Food Sci. Nutr*., **38,** 639 (1998).
14. I. C. Pappa, J. G. Bloukas, I. S. Arvanitoyannis, *Meat Sci.*, **56**, 81 (2000)
15. E. J. C. Ospina, C. A. Sierra, O. Ochoa, J. A. Pérez-Álvarez, J. ez-López, *Crit. Rev. Food Sci. Nutr*, **52**, 113 (2012).
16. B. Kılıç, C. O. Özer, *Meat Sci.*, **148**, 206 (2019).
17. T. K. Kim, H. I. Yong, S. Jung, Y. B. Kim, Y. S. Choi, *Meat sci*., **163**, 108079 (2020).
18. M. Vargas-Ramella, P. E. Munekata, M. Pateiro, D. Franco, P. C. Campagnol, I. Tomasevic, R. Domínguez, J. M. Lorenzo, *Foods*, **9**, 571 (2020).
19. E. Muguerza, O. Gimeno, D. Ansorena, J. G. Bloukas, I. Astiasarán, *Meat Sci.*, **59**, 251 (2001).
20. R. T. Heck, E. Saldaña, J. M. Lorenzo, L. P. Correa, M. B. Fagundes, A. J. Cichoski, C. R. de Menezes, R. Wagner, P. C. B. Campagnol, *Meat Sci.*, **156**, 174 (2019).
21. D. J. Bishop, D. G. Olson, C. L. Knipe, *J. Food Sci*., **58**, 484 (1993).
22. E. Muguerza, O. Gimeno, D. Ansorena, J. G. Bloukas, I. Astiasarán, *Meat Sci.,* **59**, 251 (2001).
23. D. J. Bishop, D. G. Olson, C. L. Knipe, *J. Food Sci.* **58**, 484 (1993).
24. M. C. Bourne, *Food Technol*., **32**, 62 (1978).
25. M. Bourne, Food Texture and Viscosity: Concept and Measurement, 2nd edn. London, Academic Press, Elsevier, 2002.
26. E. J. Kim, V. K. Corrigan, D. I. Hedderley, L. Motoi, A. J. Wilson, M. P. Morgenstern, *J. Texture Stud*., **40**, 457 (2009).
27. J. W. Litwinenko, A. M. Rojas, L. N. Gerschenson, A. G. Marangoni, *J. Am. Oil Chem. Soc.*, **79**, 647 (2002).
28. F. A. L. de Carvalho, P. E. Munekata, M. Pateiro, P. C. Campagnol, R. Domínguez, M. A. Trindade, J. M. Lorenzo, *LWT.*, **122**, 109052 (2020).
29. D. Martin, J. Ruiz, R. Kivikari, E. Puolanne, *Meat Sci.,* **80**, 496 (2008).
30. M. Momchilova, M. Marudova, D. Gradinarska-Ivanova, *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca: Food Science and Technology*, **79**, 67 (2022).
31. M. D. Selgas, E. Cáceres, M. L. García, *FSTI*., **11**, 41 (2005).
32. N. Ktari, S. Smaoui, I. Trabelsi, M. Nasri, R. B. Salah, *Meat Sci*., **96**, 521 (2014).
33. G. Heinz, P. Hautzinger, *FAO*, Bangkok. (2007).
34. M. T. D. Santos, V. Gerbaud, G. A. C. Le Roux, *J. Food Eng*., **12**6, 198 (2014).
35. L. Zhao, X. Peng, X. Liu, Y. Wang, S. Qin, J. Zhang, *Polym. J.,* **45**, 929 (2013).
36. J. Dreher, M. Weißmüller, K. Herrmann, N. Terjung, M. Gibis, J. Weiss, *Int. Food Res. J.*, **145**, 110416 (2021).
37. J. Dreher, M. König, K. Herrmann, N. Terjung, M. Gibis, J. Weiss, *LWT.*, **143**, 111140 (2021).
38. T. Uzlaşır, N. Aktaş, K. E. Gerçekaslan, *Food Sci. Anim. Resour*., **40**, 551 (2020).