Content is avaliable at SCOPUS

Meat Technology — Special Issue 66/3

www.meatcon.rs ▪ www.journalmeattechnology.com

UDK: 613.268:[637.5.043:636.2

ID: 179573769

https://doi.org/10.18485/meattech.2025.66.3.42

Original Scientific Paper

Application of protein concentrate-based gel emulsions for animal fat reduction in meat emulsions: proximate composition, technological, and textural properties

Nazlı Aksakal[1], *Beyza Nur Semerci*[1], *Burcu Ozturk-Kerimoglu*[1*] *and Meltem Serdaroglu*[1]

[1] *Ege University, Faculty of Engineering, Department of Food Engineering, 35100 İzmir, Türkiye*

ARTICLE INFO

Keywords:
Healthier meat products
Low-fat meat products
Plant protein concentrate
Almond
Hazelnut
Model meat system

ABSTRACT

The present study investigated the effects, on the quality of model system meat emulsions, of reducing beef fat by 50% using a gelled emulsion that contained sunflower oil plus different proteins. Meat emulsions were prepared in four different formulations as follows: 20% beef fat (control; C), 10% beef fat combined with 10% gelled emulsion containing almond protein concentrate (A50), 10% beef fat combined with 10% gelled emulsion containing hazelnut protein concentrate (H50), and 10% beef fat combined with 10% gelled emulsion containing sodium caseinate (SC50). Chemical composition, pH, water-holding capacity (WHC), and textural properties were evaluated. The highest moisture content was recorded in the H50 group (P<0.05). A50 and H50 meat emulsions contained similar protein contents as SC50, but no significant differences were recorded in the total fat content of the groups. Compared to the control, all treatments containing gelled emulsions exhibited significantly higher WHC (P<0.05), with the highest values observed in the plant protein-based meat emulsions (A50 and H50), which even surpassed the SC50 treatment (P<0.05). Texture profile analysis showed that hazelnut-based meat emulsions (H50) were of greater hardness, while almond-based meat emulsions (A50) had lower hardness (P<0.05). However, both treatments led to lower cohesiveness, springiness, and chewiness compared to the control (P<0.05). Overall, incorporating gelled emulsions into emulsified meat systems yielded beef fat substitution and supported a healthier product profile without diminishing chemical composition or functional quality.

1. Introduction

In recent years, there has been an increase in research on fat replacement strategies due to the negative health impacts of animal-derived fats present in meat and meat products. In particular, the elevated saturated fat content in these products contributes to increased low-density lipoprotein (LDL) levels, thereby heightening the risk of cardiovascular disease and posing significant concerns for human health (*Ozen et al.*, 2022). According to the World Health Organization (WHO), cardiovascular diseases remain the leading cause of death globally; in 2019, approximately 17.9 million people died from these diseases, accounting for 32% of all global deaths (*WHO*, 2021). Therefore, new strategies are being developed to reduce animal fat consumption in favor of oils rich in unsaturated fatty acids (*Badar et al.*, 2021).

***Corresponding author:** Burcu Öztürk Kerimoğlu, *burcu.ozturk@ege.edu.tr*

Paper received Jun 31st 2025. Paper accepted August 14th 2025.
The paper was presented at the 63rd International Meat Industry Conference "Food for Thought: Innovations in Food and Nutrition" – Zlatibor, October 05th-08th 2025.
Published by Institute of Meat Hygiene and Technology – Belgrade, Serbia.

Incorporating gelled emulsions is a practical and effective method in meat product reformulation, helping to improve health attributes without diminishing overall quality. A gelled emulsion forms a gel-like structure and demonstrates mechanical behavior similar to that of a viscoelastic solid (*Öztürk-Kerimoğlu et al.*, 2021). In the present study, considering the emulsifying properties of proteins, different plant-based protein concentrates (almond and hazelnut) were used in the formation of gelled emulsion systems, while a standard formulation containing sodium caseinate, a milk-derived protein, was also prepared. The preference for plant-based protein sources is significant not only from a nutritional perspective, but also in terms of sustainable food production strategies. A review of the literature suggests that protein concentrates are commonly used in the development of plant-based meat analogs (*Jia et al.*, 2021; *dos Santos et al.*, 2022; *Ramos-Diaz et al.*, 2022). However, to the best of our knowledge, no study has been conducted on substituting beef fat in meat emulsions with gelled emulsions containing almond and hazelnut protein concentrates. In this context, in the current research, we targeted a reduction in the animal fat content of meat emulsion systems through the incorporation of gelled emulsions formulated with plant-sourced proteins. This approach is expected to decrease the reliance on animal-derived fats and, consequently, mitigate the associated environmental impact.

2. Materials and methods

2.1 Preparation of plant protein concentrates, gelled emulsions, and model meat emulsions

Sodium caseinate and microbial transglutaminase (mTG) were purchased from A&D Chemicals Inc. (İstanbul, Türkiye) and SternEnzym Inc. (Ahrensburg, Germany), respectively. Raw almonds and hazelnuts, fresh and pre-packaged, were procured from the local market of İzmir, Türkiye, and ground into a fine powder using a grinder (Mioji, Türkiye). Subsequently, protein concentrates were obtained by applying the alkaline solubilization and acid precipitation method, with minor modifications, as described by *Daliri et al.* (2021). For the production of meat systems, post-mortem beef muscles (i.e., boneless round) and beef backfat were supplied from a local butcher located in İzmir, Türkiye, and transported to the laboratory under cold chain conditions. Refined sunflower oil was purchased from Migros Ticaret Inc. (İzmir, Türkiye), while the other ingredients (curing agents, etc.) were supplied by Kimbiotek Chemicals Inc. (İstanbul, Türkiye).

The oil-in-water (O/W) gelled emulsion system was prepared with some modifications of the method previously described by *Öztürk-Kerimoğlu et al.* (2021). Firstly, the water phase was prepared as follows: non-meat proteins (2.5%) were homogenized with cold water (22.5%) at 6000 rpm for 40 seconds using an Ultraturrax (IKA, Germany). Separately, mTG (0.35%) and cold water (24.65%) were mixed at the same speed and for the same duration. The two phases were then mixed at 5800 rpm for 20 seconds. Subsequently, the oil phase (50%) was added to the system in a controlled manner while mixing at 1125 rpm for 5 min. Thereafter, the emulsion was subjected to an additional homogenization at 5800 rpm for 3 min and then stored at 4°C for 12 h to enable gelation through cold setting.

Table 1 presents the formulations of model system meat emulsions. For the production of meat systems, beef and beef backfat were separately minced using a meat grinder (Arnica W2000 Grande, Türkiye) equipped with a 3 mm diameter plate. Then, the

Table 1. The formulations of model system meat emulsions

	Ingredients (g)						
Treatments*	Beef	Beef Fat	Gelled emulsion	Water (ice)	Salt (NaCl)	Sodium tripolyphosphate	Sodium nitrite
C	500	100	0.0	50	7.5	2.5	0.075
A50	500	50	50	50	7.5	2.5	0.075
H50	500	50	50	50	7.5	2.5	0.075
SC50	500	50	50	50	7.5	2.5	0.075

Legend: *C: Control meat system formulated with 20% beef fat, A50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing almond protein concentrate, H50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing hazelnut protein concentrate, SC50: 10% beef fat and 10% gelled emulsion containing sodium caseinate.

minced meat was pre-mixed at 500 rpm for 1 min in a food processor (Thermomix TM5, Vorwerk, Germany). Next, the other ingredients were added, and the mixture was homogenized under the same conditions for 2 min. After partially adding the ice and the lipid phase (fat or gelled emulsion), the mixture was further mixed at 1100 rpm for 3 min. After adding the remaining ice, an additional mixing step was performed at the same speed. Finally, the emulsification was completed by mixing at 2000 rpm for 1 min to obtain the final model meat emulsion.

2.2 Analyses

Total protein content was determined using the Kjeldahl method, as described by *Moore* (2010), by multiplying the nitrogen content by the nitrogen-to-protein conversion factor (6.25). Moisture and ash content were measured according to *AOAC* (2012). pH value was measured using a WTW pH 3110 Set 2 pH meter (WTW, Germany). Water-holding capacity (WHC) was measured after heat treatment and centrifugation of the samples, based on the method described by *Hughes et al.* (1997) with minor modifications. Texture profile analysis (TPA) of the model meat emulsions, presenting hardness, cohesiveness, springiness, gumminess, and chewiness, was carried out using a texture analyzer (TA-XT2, Stable Micro Systems, Haslemere, UK) by compressing suitable samples to 50% of their original height using a 30 kg load cell, at a crosshead speed of 1 mm/s. The pre-test and post-test speeds were set at 1 mm/s and 5 mm/s, respectively. Statistical analysis was performed by analysis of variance (ANOVA) followed by Duncan's post-hoc tests in the SPSS software (v.26, IBM, USA) within a confidence interval of 95%. All the analyses were performed at least in triplicate. Mean values are presented and discussed below.

3. Results and discussion

3.1 Chemical composition and pH

Proximate composition and pH values of the model meat systems are presented in Table 2. Moisture content is a key quality indicator that determines the WHC and emulsification properties of meat products; hence, high moisture content plays a key role in preserving the functional properties of the product (*Qiao et al*., 2001). Total moisture contents of the model meat emulsions were between 63.49-66.47%, and the lowest moisture content was found in the control (C) group, while the highest mean moisture content was recorded in the H50 meat emulsion with hazelnut protein concentrate ($P<0.05$). The findings indicated that gelled emulsions containing hazelnut protein have the potential to enhance water retention in meat systems and entrap water within the emulsified meat matrix. Formerly, *dos Santos et al.* (2022) mentioned that the moisture content of the final product could be improved by increasing WHC and emulsion stability through the use of concentrations.

The protein contents of the treatments ranged between 19.65-21.03%, and indeed, almond and hazelnut meat emulsions had similar protein contents to that of the sodium caseinate meat emulsion. Although the model meat emulsions with plant-sourced proteins had lower protein contents than the control ($P<0.05$), the plant-derived components were mentioned as having the potential to improve gel formation and emulsion stability (*Toldrá*, 2006). Thus, the functional properties of proteins should also be considered as quality-determining factors alongside total protein content (*Toldrá*, 2006).

The fat content of the treatments ranged between 9.47%-11.76%, and no statistically significant differences were observed between the groups (Table 2). In a study conducted by *Ghribi et al.* (2018), sausages were formulated using different concentrations of chickpea protein concentrate, with fat contents ranging from 14.27% to 19.04%. The absence of differences in total fat content among the groups in our study is attributed to the fixed total lipid concentration used in the formulation (20%). Under these conditions, the similar fat levels in the model meat emulsions suggest that the gelled emulsion treatments exhibited a fat retention capacity comparable to the control, indicating a technological advantage. However, to ensure lipid modification, further analysis of the fatty acid composition and unsaturated fatty acid levels is required.

The ash contents of the model meat emulsions were between 3.41-4.70%. The ash contents of the gelled emulsion groups, in which animal fat was reduced, were similar to that of the control.

The pH of the model meat emulsions ranged between 5.85-6.10. The lowest pH belonged to the control meat emulsion group ($P<0.05$), indicating that utilization of gelled emulsions with different protein concentrates effected a rise in pH in each of the other groups. The pH values measured in our model meat emulsions were consistent with those

Table 2. Chemical composition and pH value of model system meat emulsions

Treatments*	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	pH
C	63.49^{c}±0.30	11.76±0.96	21.03^{a}±0.65	3.71^{ab}±0.0	5.85^{b}±0.13
A50	65.29^{b}±0.05	10.0±0.62	19.90^{b}±0.19	4.54^{ab}±0.38	6.07^{a}±0.05
H50	66.47^{a}±0.004	10.96±1.26	19.65^{b}±0.12	3.41^{b}±0.70	6.13^{a}±0.17
SC50	65.62^{b}±0.26	9.47±0.48	20.25^{ab}±0.30	4.70^{a}±0.25	6.10^{a}±0.01

Legend: *C: Control meat system formulated with 20% beef fat, A50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing almond protein concentrate, H50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing hazelnut protein concentrate, SC50: 10% beef fat and 10% gelled emulsion containing sodium caseinate.

reported in a study that used soy, pea and sunflower protein concentrates in hybrid meat emulsions (*dos Santos et al.*, 2022). The pH level in meat products is a critical factor that directly affects basic quality parameters such as color, WHC, and tenderness, thereby determining both the functional and sensory characteristics of the final product.

3.2 Water-holding capacity (WHC)

The WHC of the control, A50, H50, and SC50 model meat emulsions was determined to be 68.42%, 80.85%, 81.97%, and 76.06%, respectively (Figure 1). Compared to the control group, significantly higher WHCs were observed in all treatments with gelled emulsions (P<0.05). The highest WHC was recorded in model meat emulsions with plant-proteins (A50 and H50), and these treatments even presented higher WHCs than the SC50 meat emulsion containing sodium caseinate (P<0.05). Accordingly, it was shown that gelled emulsions prepared with either of the plant protein concentrates have good potential to raise the WHC of the emulsified model meat systems, thereby improving technological quality and product yield. The high WHC can provide significant technological and economic advantages in meat emulsions. Formerly, *Nacak et al.* (2021) reported that increasing the added level of gelled emulsions in sausage formulations considerably increased the WHC of the emulsions, and the main reason for this was attributed to the water-binding properties of the protein-based ingredients in the gelled emulsion, such as gelatin and egg white powder. WHC is a fundamental technological feature that improves the textural quality of meat products and reduces weight loss during cooking, thereby determining both production efficiency and consumer satisfaction (*Huff-Lonergan and Lonergan*, 2005).

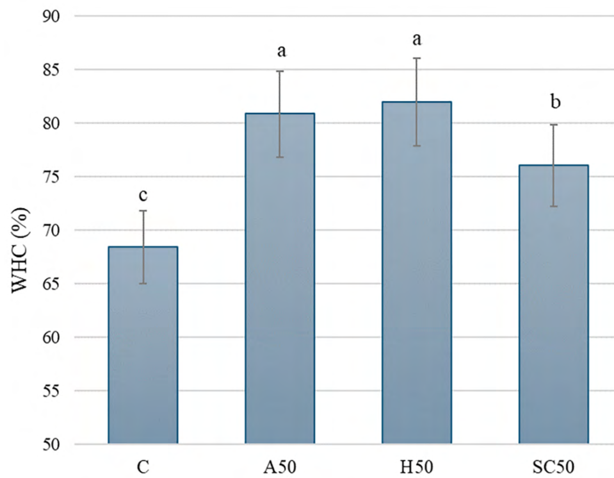

Figure 1. WHC of model system meat emulsions (%)

Legend: *C: Control meat system formulated with 20% beef fat, A50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing almond protein concentrate, H50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing hazelnut protein concentrate, SC50: 10% beef fat and 10% gelled emulsion containing sodium caseinate.

3.3. Texture

As shown in Table 3, the model meat emulsion systems exhibited significant differences in hardness, cohesiveness, springiness, gumminess, and chewiness (*P*< 0.05). Hardness results revealed that the highest value among treatments was found in H50 model meat emulsions, while the lowest values were observed in control and A50 meat emulsions (P<0.05). It was reported that the hardness of meat emulsions increases with higher protein content (*Santhi et al.*, 2017). However, in our study, the protein content of the harder H50 group was not higher when compared with the other groups. In this situation, it is suggested that the fibrous structure formed a complex network in this group due to its ability to retain water, thereby resulting in greater hardness.

A50 and H50 meat emulsions had similar cohesiveness values, which were both lower than the control (P<0.05). In contrast, *Yang et al*. (2025) reported that replacing pork fat with almond protein isolate-based Pickering emulsions in pork sausage formulations significantly increased cohesiveness. The differing results observed in our study are likely attributable to variations in the behavior of pork versus beef fat, as well as differences in the fat replacer emulsion systems employed.

Springiness was the highest in the C group among treatments (P<0.05), so the extent of recovery of the sample height was the highest in this treatment (*Fan et al*., 2020). This outcome was likely due to the rigid structure of animal fat compared to the pastry-like structure of the gelled emulsions.

The A50 group exhibited the lowest gumminess among treatments (P<0.05), which pointed to a lower energy requirement for mastication due to a softer and less dense texture. Chewiness values of A50 and H50 meat emulsions were significantly lower than those of the C and SC50 model meat emulsions ($P < 0.05$). These findings were in line with the softness of the meat emulsion containing gelled emulsions with almond protein (A50). However, although H50 meat emulsions with hazelnut protein had higher hardness, the lower chewiness of this group was due to the lower cohesiveness and springiness (compared with other treatments). Chewiness can be affected by the moisture-to-protein ratio of the product, with higher ratios typically resulting in less chewiness (*Nacak et al*., 2021). This trend was also reflected in the results of the current study. TPA is widely used to characterize the textural attributes of meat emulsions and serves as a reliable indicator of their overall quality (*Lee et al*., 2025).

4. Conclusion

The findings of the present study indicated that utilization of gelled emulsions formulated with plant-based protein sources is an effective way to reduce animal fat in emulsified meat systems. The studied formulations containing almond and hazelnut protein concentrates provided promising results in terms of technological functionality and product yield of the model meat emulsions. Although textural differences were evident among treatments, the incorporation of plant protein-based emulsions successfully supported fat reduction without compromising the functional qualities measured, so this approach would thereby contribute to healthier meat product formulations. Future research should focus on optimizing the fatty acid composition and exploring both sensory attributes and oxidative quality in meat products formulated with gelled emulsion systems containing different plant proteins.

Table 3. Textural parameters of model system meat emulsions

Treatments*	Hardness (N)	Cohesiveness	Springiness (mm)	Gumminess (N)	Chewiness (N x mm)
C	11.26^{c}±0.48	0.22^{a}±0.04	0.24^{a}±0.03	2.54^{a}±0.51	0.62^{a}±0.20
A50	9.33^{c}±1.17	0.15^{b}±0.05	0.13^{c}±0.02	1.41^{b}±0.64	0.17^{c}±0.04
H50	18.07^{a}±1.87	0.15^{b}±0.02	0.13^{c}±0.02	2.80^{a}±0.54	0.38^{bc}±0.12
SC50	13.95^{b}±0.39	0.19^{ab}±0.02	0.18^{b}±0.02	2.61^{a}±0.23	0.48^{ab}±0.07

Legend: *C: Control meat system formulated with 20% beef fat, A50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing almond protein concentrate, H50: Reduced-fat meat system formulated with 10% beef fat and 10% gelled emulsion containing hazelnut protein concentrate, SC50: 10% beef fat and 10% gelled emulsion containing sodium caseinate.

Disclosure Statement: No potential conflict of interest was reported by authors.

References

AOAC, (2012). Official Methods of Analysis, Latimer, G.W. (Ed.), 19th ed. Association of Official Analytical Chemists, Gaithersburg, MD, USA.

Badar, I. H., Liu, H., Chen, Q., Xia, X., & Kong, B. (2021). Future trends of processed meat products concerning perceived healthiness: A review. *Comprehensive Reviews in Food Science and Food Safety*, 20(5), 4739–4778. https://doi.org/10.1111/1541-4337.12813

Daliri, H., Ahmadi, R., Pezeshki, A., Hamishehkar, H., Mohammadi, M., Beyrami, H., Heshmati, M. K., & Ghorbani, M. (2021). Quinoa bioactive protein hydrolysate produced by pancreatin enzyme-functional and antioxidant properties. *LWT- Food Science and Technology*, 150, 111853. https://doi.org/10.1016/j.lwt.2021.111853

dos Santos, M., da Rocha, D. A. V. F., Bernardinelli, O. D., Oliveira Junior, F. D., de Sousa, D. G., Sabadini, E., da Cunha, R. L., Trindade, M. A., & Pollonio, M. A. R. (2022). Understanding the performance of plant protein concentrates as partial meat substitutes in hybrid meat emulsions. *Foods*, 11(21), 3311. https://doi.org/10.3390/foods11213311

Fan, R., Zhou, D., & Cao, X. (2020). Evaluation of oat β-glucan-marine collagen peptide mixed gel and its application as the fat replacer in the sausage products. *PloS One,* 15, 1–14. https://doi.org/10.1371/journal.pone.0233447

Ghribi, A. M., Amira, A. B., Gafsi, I. M., Lahiani, M., Bejar, M., Triki, M., Zouari, A., Attia, H., & Besbes, S. (2018). Toward the enhancement of sensory profile of sausage "Merguez" with chickpea protein concentrate. *Meat Science*, 143, 74–80. https://doi.org/10.1016/j.meatsci.2018.04.025

Hughes, E., Cofrades, S., & Troy, D. J. (1997). Effects of fat level, oat fibre and carrageenan on frankfurters formulated with 5, 12 and 30% fat. *Meat Science*, 45(3), 273–281. https://doi.org/10.1016/S0309-1740(96)00109-X

Huff-Lonergan, E., & Lonergan, S. M. (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. *Meat Science*, 71(1), 194-204. https://doi.org/10.1016/j.meatsci.2005.04.022

Jia, W., Curubeto, N., Rodríguez-Alonso, E., Keppler, J. K., & van der Goot, A. J. (2021). Rapeseed protein concentrate as a potential ingredient for meat analogues. *Innovative Food Science & Emerging Technologies*, 72, 102758. https://doi.org/10.1016/j.ifset.2021.102758

Lee, J. A., Kang, K. M., & Kim, H. Y. (2025). Changes in physicochemical characteristics of goat meat emulsion-type sausage according to the ratio of fat and water contents. *Food Science of Animal Resources*, 45(3), 794–806. https://doi.org/10.5851/kosfa.2024.e61

Moore, J. C., DeVries, J. W., Lipp, M., Griffiths, J. C., & Abernethy, D. R. (2010). Total protein methods and their potential utility to reduce the risk of food protein adulteration. *Comprehensive Reviews in Food Science and Food Safety*, 9(4), 330–357. https://doi.org/10.1111/j.1541-4337.2010.00114.x

Nacak, B., Öztürk-Kerimoğlu, B., Yıldız, D., Çağındı, Ö., & Serdaroğlu, M. (2021). Peanut and linseed oil emulsion gels as potential fat replacer in emulsified sausages. *Meat Science*, 176, 108464. https://doi.org/10.1016/j.meatsci.2021.108464

Ozen, E., Mihaylova, R., Weech, M., Kinsella, S., Lovegrove, J. A., & Jackson, K. G. (2022). Association between dietary saturated fat with cardiovascular disease risk markers and body composition in healthy adults: findings from the cross-sectional BODYCON study. *Nutrition & Metabolism*, 19(1), 15. https://doi.org/10.1186/s12986-022-00650-y

Öztürk-Kerimoğlu, B., Kavuşan, H. S., Benzer Gürel, D., Çağındı, Ö., & Serdaroğlu, M. (2021). Cold-set or hot-set emulsion gels consisted of a healthy oil blend to replace beef fat in heat-treated fermented sausages. *Meat Science*, 176, 108461. https://doi.org/10.1016/j.meatsci.2021.108461

Qiao, M., Fletcher, D. L., Smith, D. P., & Northcutt, J. K. (2001). The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. *Poultry Science*, 80(5), 676–680. https://doi.org/10.1093/ps/80.5.676

Ramos-Diaz, J. M., Kantanen, K., Edelmann, J. M., Jouppila, K., Sontag-Strohm, T., & Piironen, V. (2022). Functionality of oat fiber concentrate and faba bean protein concentrate in plant-based substitutes for minced meat. *Current Research in Food Science*, 5, 858–867. https://doi.org/10.1016/j.crfs.2022.04.010

Santhi, D., Kalaikannan, A., & Sureshkumar, S. (2017). Factors influencing meat emulsion properties and product texture: A review. *Critical Reviews in Food Science and Nutrition*, 57(10), 2021–2027. https://doi.org/10.1080/10408398.2013.858027

Toldrá, F. (2006). The role of muscle enzymes in dry-cured meat products with different drying conditions. *Trends in Food Science & Technology*, 17(4), 164–168. https://doi.org/10.1016/j.tifs.2005.08.007

WHO, (2021). World Health Organization. *Cardiovascular diseases (CVDs)*. Retrieved from https://www.who.int/newsroom/fact-sheets/detail/cardiovascular-diseases-(cvds). Accessed July 29, 2025.

Yang, Q., Han, P., Qi, W., Shao, Y., Zhang, X., Wu, F., & Zhang, Z. (2025). High internal phase Pickering emulsion by ultrasound-modified almond protein isolate particles as a new fat substitute to improve oxidative stability of pork sausages. *Frontiers in Sustainable Food Systems*, 9, 1529154. https://doi.org/10.3389/fsufs.2025.1529154

Authors info

Nazlı Aksakal, https://orcid.org/0009-0001-8878-5900
Beyza Nur Semerci, https://orcid.org/0009-0004-7446-6476
Burcu Ozturk-Kerimoglu, https://orcid.org/0000-0001-9777-8510
Meltem Serdaroglu, https://orcid.org/0000-0003-1589-971X