Impact of thermal processing on the nutritional and chemical composition of edible snail meat (*Helix aspersa maxima*)

Mihail Garkov[1], *Miroslava* Kakalova [2], and *Kremena* Nikovska[1*]

[1] Department of Tourism and Culinary Management, Faculty of Economics, University of Food Technologies, Plovdiv, Bulgaria

[2] Department of Analytical chemistry and physical chemistry, Faculty of Technology, University of Food Technologies, Plovdiv, Bulgaria

Abstract. A comparative study was carried out to assess the effect of different thermal processing methods on the nutritional value and chemical composition of edible snail meat (*Helix aspersa maxima*). The experimental design included sous-vide treatment at 80 °C for 200 minutes, conventional boiling at atmospheric pressure and boiling under high pressure. The results demonstrated that the applied thermal treatments strongly influences the nutritional profile and chemical composition of cooked snail meat. Compared to other thermal processing techniques, the sous-vide method most effectively preserves the content of proteins, fats, minerals, and carbohydrates whereas boiling at high pressure produces snail meat characterized by comparatively higher concentrations of essential amino acids and polyunsaturated fatty acids. Sous-vide, as a contemporary culinary technique, presents additional technological and quality-related advantages, making it a promising method for the preparation of snail meat.

1 Introduction

Thermal processing has a significant impact on the nutritional value and chemical composition of food products, and this effect is the focus of extensive scientific investigation, particularly in relation to non-traditional protein sources such as edible snails. Research indicates that cooking methods can lead to substantial alterations in the nutrient profile of cooked foods. The high-temperature cooking processes, such as boiling, can result in protein denaturation, which subsequently reduces the solubility and availability of these proteins for human consumption. This effect is evident in fish and other meats [25].

Thermal treatment of food serves multiple purposes, including the enhancement of sensory properties, digestibility, and the inactivation of microorganisms, thereby ensuring food safety and extending shelf life [1]. Studies have shown that the application of thermal treatments results in significant changes in the nutrient profiles of muscle foods such as meat and seafood, particularly regarding protein denaturation and lipid oxidation [1, 27]. The implications for edible snails, which share similar proteinaceous compositions, suggest that cooking methods could lead to a decrease in protein digestibility and an alteration of essential fatty acid profiles. Additionally, the review by [27] discussed the structural changes that proteins undergo when exposed to heat, including alterations to their secondary and tertiary configurations. Given that the muscle tissues of snails are primarily composed of protein, it is plausible that similar structural changes occur, which could affect muscle tenderness and overall palatability, further influencing consumer preferences.

In the context of edible snails, the existing literature reveals some studies detailing their nutritional value and chemical composition post-processing. The thermal process plays a role in enhancing or diminishing the sensory properties of snails. The texture and palatability, which are critical for consumer acceptance, can change as proteins coagulate during thermal processing, affecting the food's overall appeal [25]. Culinary traditions around the world demonstrate the cultural significance of snail dishes, such as France's escargots in garlic butter or Thailand's Gaeng-Kui-Hoi-Khom, illustrating the importance of cooking methods in delivering both flavor and nutritional content [28]. Thus, thermal treatment not only affects nutrient retention but also influences the broader contexts of food culture and cuisine.

Furthermore, the nutritional profile of snails can be beneficial due to their unique biochemical composition. They are a rich source of essential fatty acids and proteins. However, specific studies indicate that geographical and environmental factors, such as the bioaccumulation of selenium from their habitats, can influence the nutrient levels in their meat [18]. This suggests that the impact of thermal treatment on the nutritional value of edible snails is multifaceted, involving both inherent biochemical properties and external variables introduced by cooking methods. A notable study by [20] directly delved into different cooking methods, particularly boiling, and their

* Corresponding author: k_nikovska@uft-plovdiv.bg

effects on the nutrient composition of the small brown snail (*Cornu aspersum aspersum*). The authors found that boiling demonstrated a significant change in its proximate composition, notably enhancing calcium and phosphorus levels while reducing overall cholesterol content. Such alterations in nutritional indices suggest that thermal processing could reinforce the dietary value of snails, particularly concerning mineral intake. Additionally, studies on other food items, such as golden pomfret, emphasize a correlation between cooking methods and flavor development as well as nutritional changes [26]. The authors noted a connection between fatty acid oxidation and the flavor of cooked products. This suggests that flavor profiles in snails may similarly be influenced by cooking techniques, contributing to their overall appeal in culinary applications. Further, the flavor of edible snails can enhance consumer acceptance, indicating a practical aspect to consider in cooking practices.

Various studies have reported on the nutritional advantages of consuming snails, including their high protein content and essential fatty acids. Milinsk et al., [23] indicated that the fatty acid profiles of snails can be favorable when raised under optimal conditions, suggesting that both the quality of feed and cooking methods are crucial for maximizing their health benefits. The presence of polyunsaturated fatty acids (PUFAs) in snail meat highlights the significance of selecting appropriate cooking methods that do not adversely affect these nutrients. The comparative analysis of how different cooking methods affect edible snails can further benefit from examining the microflora levels, which must be adequately managed to ensure food safety.

Yıldırım et al., [10] investigated the safety of wild terrestrial snails in Northern Cyprus and noted that thorough cooking could significantly mitigate parasite risks, highlighting the critical intersection between culinary practices and health implications. This idea is particularly significant for snail species, where proper preparation is vital for safety and health.

The complex interactions between thermal treatment, nutrient bioavailability, and chemical composition in edible snails illuminate significant areas for future research. Variations in methodology, treatment durations, and temperatures need comprehensive exploration to fully understand the implications for health and nutrition. Emphasizing this complexity not only enhances food safety but also the potential for utilizing edible snails in the modern diet.

The aim of the study is to evaluate the effect of different thermal processing methods on the chemical composition of snail meat, with the objective of identifying the optimal method that best preserves its nutritional value.

2 Materials and methods

2.1. Materials

Snail Meat

For the purposes of this study, meat from *Helix aspersa maxima* snails, belonging to the class Gastropoda, was used. A total of 900 specimens from the same batch, each with an individual weight of 6.09 ± 0.50 g, were obtained from the "Eco-Telus" snail farm located in the village of Bulgarevo, Kavarna Municipality, Bulgaria. The snails were reared using a semi-intensive farming method and were fed certified feed. After harvesting, the snails were euthanized in an autoclave at 90 °C for 10 minutes, after which their shells were manually removed. The meat was frozen in a blast chiller at -24 °C and stored and transported at -18 °C.

2.2. Methods

2.2.1. Sample Preparation

Frozen snail meat samples were thawed under refrigerated conditions at 4 °C for 24 hours. All samples were thermal threated on the day of thawing.

2.2.2. Thermal Processing Methods

Boiling at Atmospheric Pressure. Snail meat (4 °C) with a total weight of 192 g was fully submerged in a medium with an initial temperature of 18 °C, which reached 97 °C within 235 seconds. Thermal processing was carried out for 95 minutes at atmospheric pressure. Temperature was monitored throughout the process using a wireless digital probe Meater 2 (Apption Labs, USA). Samples were stored at 3 °C ± 2 °C. All analyses were conducted within 24 hours after thermal processing.

Boiling at High Pressure. Snail meat (4 °C) with a total weight of 198 g was fully submerged in a medium with an initial temperature of 18 °C, reaching 111 °C within 180 seconds. Thermal processing was performed at a pressure of 148 kPa for 45 minutes. Temperature was continuously monitored using a wireless digital probe Meater 2 (Apption Labs, USA). Samples were stored at 3 °C ± 2 °C. All analyses were performed within 24 hours after thermal processing.

Sous Vide Processing. Sous vide processing was conducted in a thermostatic water bath Julabo SW23 (23 L total volume). Snail meat was thermally treated at 80 °C for 200 minutes. After processing, the samples were removed and cooled in an ice bath to 4 °C ± 2 °C for 6 minutes. Temperature was monitored throughout the process using a wireless digital probe Meater 2 (Apption Labs, USA). Samples were stored at 3 °C ± 2 °C for up to 30 days.

2.2.3. Determination of Protein Content

The protein content in raw and thermally processed products was determined using the Kjeldahl method, based on the determination of total nitrogen [13].

2.2.4. Determination of Fat Content

Fat content was determined by the Soxhlet extraction method, based on the extraction of lipids using diethyl ether [12].

2.2.5. Determination of Total Carbohydrates

Total carbohydrate content in the analyzed samples was determined iodometrically, following acid hydrolysis to monosaccharides using concentrated hydrochloric acid, and subsequent titration of the hydrolysate with a standard sodium thiosulfate solution.

2.2.6. Fatty Acid Composition

Fatty acid composition was analyzed at the laboratory of the AgroBioInstitute in Sofia, Bulgaria. The fatty acid profile was determined using a gas chromatograph 7890A (Agilent Technologies Inc., USA) equipped with a mass selective detector (MSD) 5975C and an HP-5 ms capillary column (30 m length × 0.32 mm internal diameter × 0.25 µm film thickness) (ISO 12966-4:2015). The results are expressed as a percentage of total fatty acids.

2.2.7. Amino Acid Composition

Amino acid composition was analyzed using an automatic amino acid analyzer following acid hydrolysis of the samples at 110 °C for 24 hours with 6 M HCl containing 0.5% 2-mercaptoethanol. After rehydrolysis with 0.02 M HCl and filtration through a 0.45 µm membrane filter, the samples were analyzed for amino acid content. The results are expressed as a percentage of the total identified amino acids.

2.2.8. Statistical analysis

Data from three independent replications ($n = 3$) are presented as mean ± standard deviation. Summary statistics were computed for each dependent variable. Nutrients, fatty and amino acids were evaluated using One-way ANOVA, followed by Tukey's HSD to test the significant effect of cooking at a threshold of $p < 0.05$.
Means in the same row with different superscripts in the lowercase letter on tables are statistically significantly different ($p < 0.05$).

3 Results and Discussion

3.1. Macronutrients

The composition of heat-treated meat from farmed *Helix aspersa maxima* snails, reared in Bulgaria, was investigated, and the results are presented in Table 1. The used thermal processing methods reflect some technological approaches. Boiling at atmospheric pressure is a traditional and widely used method in culinary practice and serves as a reference point for comparison. Pressure boiling is a more industrially applicable method that reduces thermal processing time. Sous vide is a contemporary and soft technique, in which food is cooked at lower temperatures over extended periods. The parameters of 80 °C for 200 minutes for sous vide processing of snail meat are scientifically justified, as they ensure microbiological safety and preserve nutritional value. Similar parameters are applied in scientific research and culinary practice for processing various food products [2, 4, 7, 9, 21, 22, 29], which allows for comparability and consistency with data reported in the literature.

Concerning moisture content, thermal processing typically results in the evaporation of water from food products. This effect can vary with the duration and intensity of the heat applied. For instance, cooking methods such as frying can lead to substantial moisture reduction, while methods like steaming may preserve more moisture due to shorter cooking times at lower temperatures [1]. Thermal processing method had a significant impact on the proximate composition of the snail meat. On a fresh weight basis, sous vide resulted in higher moisture retention (77.2%) compared with both atmospheric and high-pressure boiling (~74%). This outcome is consistent with previous reports that vacuum-sealed, low-temperature cooking minimizes evaporative losses, whereas boiling promotes greater water migration due to exposure to steep thermal gradients and a surrounding water medium [5, 16].

The protein content in the heat-treated samples is high and is significantly affected by the type of thermal processing. When expressed on a dry matter basis, the protein content is lowest in conventionally boiled snail meat (Table 1). Thermal treatment can lead to protein denaturation, which may initially reduce the protein's functional capacity but often enhances digestibility [6, 27]. Cooking methods that involve high temperatures, such as roasting and boiling, can also result in the degradation of essential amino acids due to the formation of cross-links or reactive compounds that decrease protein bioavailability [27]. The present study demonstrates that the applied heat treatment methods and the technological parameters (time and temperature) affect the protein content in snail meat. Protein retention followed a consistent pattern across both fresh and dry weight bases, with the highest values in sous vide, intermediate in high-pressure boiling, and the lowest in atmospheric boiling.

The greater reduction observed in atmospheric boiling may be linked to solvent–protein interactions compared with the sealed, water-excluded sous vide environment.

Fat content is notably influenced by thermal processes. The low fat content in the analyzed samples represents a significant advantage. Fat content was also significantly higher in sous vide samples on both a fresh and dry weight basis (Table 1). This observation is consistent with reports that sous vide minimizes lipid solubilization and oxidation by preventing direct water contact and limiting oxygen availability [19].

By contrast, both atmospheric and high-pressure boiling facilitate lipid loss either through solubilization in the cooking medium or oxidative pathways enhanced at elevated temperatures.

Table 1. Nutritional/Energy Value of Heat-Treated Snail Meat, %

Indicators	Sous vide		Boiling (at atmospheric pressure)		Boiling (at high pressure)	
	fw*	dw**	fw*	dw**	fw*	dw**
Moisture	77,21b ± 0,38	-	74,06a ± 0,55	-	74,63a ± 0,66	-
Proteins	13,92a ± 0,11	61,08d ± 0,12	14,32b ± 0,08	55,20e ± 1,44	14,74c ± 0,09	58,09f ± 1,13
Fats	1,61a ± 0,06	7,06d ± 0,22	1,38b ± 0,01	5,32e ± 0,31	1,30b ± 0,05	5,12e ± 0,55
Ash content	2,21a ± 0,05	9,70d ± 0,16	2,10b ± 0,02	8,10e ± 0,02	2,02c ± 0,04	7,96f ± 0,22
Total carbohydrates	1,11a ± 0,03	4,83b ± 0,18	1,05a ± 0,04	4,05c ± 0,32	0,98a ± 0,04	3,86d ± 0,05
Energy value, kcal/100g	**74,79**	-	**73,90**	-	**74,58**	-

Means in the same row with different superscripts in the lowercase letter are statistically significantly different ($p < 0.05$).
* fw – values calculated on a fresh weight basis.
** dw – values calculated on a dry weight basis.

Mineral (ash) content exhibited similar treatment-related differences, with the greatest retention in sous vide samples and the most substantial reductions under high-pressure boiling. Mineral leaching into the surrounding water during boiling is a well-established mechanism, and elevated pressure is known to accelerate mass transfer processes [24].

The carbohydrate content of the heat-treated samples is also low (Table1). Carbohydrate retention was greatest in sous vide preparations, with high-pressure boiling producing the most pronounced reductions. This is likely attributable to enhanced solubilization and diffusion of low-molecular-weight carbohydrates into the cooking water under pressure. Notably, differences among treatments were statistically significant on a dry weight basis but not on a fresh weight basis, suggesting that moisture loss during boiling may partly mask compositional changes when expressed relative to fresh tissue mass.

The high water content, high protein levels, and reduced fat and carbohydrate contents observed in the studied snails make them an excellent source of protein and essential nutrients.

3.2. Amino Acid Profile

Snail meat, particularly from species like *Helix aspersa*, is recognized for its nutritional value, including high protein content and essential fatty acids. It has been reported that consumption of garden snails can fulfill approximately 30% of the daily essential amino acid requirements for a 75 kg adult when consumed in sufficient quantities, emphasizing the nutritional importance of this protein source [8].

Understanding how various cooking methods can modify the nutritional profile of snail meat can provide significant insights for both food science and culinary practices. An essential aspect of thermal cooking methods is their differential impact on amino acid retention.

The amino acid composition of thermally processed snail meat is presented in Table 2. The amino acid profile of *Helix aspersa maxima* meat reveals a diverse composition that is essential for various biological functions. It was shown that essential amino acids are best preserved during thermal processing involving cooking at high pressure.

Among the essential amino acids, arginine and leucine are present in significant amounts, and their concentrations are not notably affected by the type of thermal treatment applied. The high levels of valine and phenylalanine in the heat-treated meat indicate that these amino acids are stable across different cooking methods. The type of thermal processing does not significantly influence their concentrations. Kim et al., [11] found that different cooking methods can significantly influence the amino acid profiles of meats, including adjustments in the water retention capacity and thermal denaturation of proteins, which subsequently affects nutrient content.

The profile of essential amino acids in the meat remains relatively unchanged regardless of the applied heat treatment. The results demonstrate a relatively high concentration of flavor-enhancing amino acids such as glutamic and aspartic acid in the total protein. These amino acids contribute to the umami taste [14], enriching the sensory characteristics of snail meat.

In thermally processed snail meat, the levels of these amino acids are not affected by the processing method used. Analyses of the amino acid composition of certain red meats indicate that glutamic acid is the most abundant in camel meat [3] and bison meat [17].

Through its rich amino acid profile, the meat of *Helix aspersa maxima* provides the essential amino acids required to support health and physical fitness.

Table 2. Amino acid profiles of cooked snail meat

Amino Acids	**Sous vide***	**Boiling at atmospheric pressure***	**Boiling at high pressure***
Arginine	4,89a±0,07	5,01a ± 0,49	5,15 a± 0,41
Histidine	1,11a±0,15	1,14a ± 0,09	1,31a ± 0,11
Isoleucine	3,30a±0,07	3,38a ± 0,32	3,87a ± 0,35
Leucine	4,79a±0,11	4,92a ± 0,23	5,52a ± 0,33
Lysine	3,23a±0,20	3,31a ± 0,51	3,79a ± 0,23
Phenylalanine	4,20a±0,21	4,30a ± 0,36	4,93a ± 0,19
Threonine	0,87a±0,18	0,89a ± 0,01	1,02a ± 0,21
Valine	4,29a±0,06	4,39a ± 0,44	5,03a ± 0,39
Methionine	0,71a±0,18	0,73a ± 0,11	0,84a ± 0,09
Essential amino acids	**27,39**	**28,09**	**31,47**
Alanine	5,19a±0,12	4,07b ± 0,08	3,90b ± 0,15
Aspartate	7,21a±0,58	6,64a ± 0,99	6,13a ± 0,67
Glutamate	9,79a±0,47	7,37b ± 0,83	8,68a ± 0,61
Glycine	4,86a±0,77	3,83a ± 0,67	3,62a ± 0,34
Pyroglutamic	0,67a±0,09	0,53a ± 0,05	0,58a ± 0,02
Proline	3,05a±0,40	2,40a ± 0,15	2,02a ± 0,22
Serine	0,15a±0,02	0,12a ± 0.01	0,07a ± 0,01
Tyrosine	2,20a±0,25	1,73a ± 0,12	1,32a ± 0,11
Cysteine	0,40a±0,10	0,31a ± 0,11	0,17a ± 0,03
Glutamine	0,15a±0,02	0,12a ± 0,01	0,12a ± 0,02
Nonessential amino acids	**33,68**	**27,11**	**26,63**

Means in the same row with different superscripts in the lowercase letter are statistically significantly different ($p < 0.05$).
* Expressed as a percentage of the total protein in the dry matter

Its high content of these amino acids makes it suitable for specialized diets and for individuals engaged in intense physical activity. The lack of significant impact of different thermal processing methods (sous vide, boiling at atmospheric pressure, and pressure cooking) on the amino acid profile of snail meat is likely due to the stability of amino acids at moderate temperatures. The applied methods involve temperature ranges that do not induce substantial degradation or transformation of amino acids. Another probable explanation is the homogeneous structure and high water content of snail meat, which ensures uniform heat distribution and prevents localized overheating.

3.3. Fatty Acid Composition

The fatty acid composition of thermally threated snail meat was investigated. The fatty acid profile of *Helix aspersa maxima* includes three main categories: saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). In snail meat, polyunsaturated fatty acids predominate, with the highest content observed in samples boiled with high pressure, comprising 42.56% of the total fatty acid content (Table 3). This proportion is lower in sous-vide cooked meat.

The polyunsaturated fatty acid profile in *Helix aspersa maxima* meat demonstrates considerable diversity, with linoleic acid (C18:2) showing the highest content—18.73% and 17.79% in high pressure cooking and atmospheric boiling, respectively. Eicosadienoic acid (C20:2) is also present in high amounts across all three thermal cooking methods. Both acids belong to the omega-6 fatty acid group.

Table 3 Fatty acid profiles of cooked snail meat

Fatty acids	Sous vide*	Boiling at atmospheric pressure*	Boiling at high pressure*
Myristic acid C14:0	0,75a ± 0,07	0,38b ± 0,02	0,51a ± 0,02
Pentadecanoic acid C15:0	0,18a ± 0,04	0,15a ± 0,01	0,28a ± 0,02
Palmitic acid C16:0	15,70a ± 0,13	13,59a ± 0,29	12,00b ± 0,22
Heptadecanoic acid C17:0	1,95a ± 0,07	2,18a ± 0,17	2,29a ± 0,12
Stearic acid C18:0	17,68a ± 0,19	14,05b ± 0,47	11,82c ± 0,19
Arachidic acid C20:0	1,45a ± 0,13	1,22a ± 0,14	1,07a ± 0,05
Total Saturated Fatty Acids	**37,71**	**31,57**	**27,97**
Oleic acid C18:1	26,19a ± 0,24	28,00b ± 0,61	29,47b ± 0,53
Total MUFA	**26,19**	**28,00**	**29,47**
Linoleic acid C18:2 ω-6	15,89a ± 0,22	17,79b ± 0,12	18,73b ± 0,15
cis-11,14-Eicosadienoic acid C20:2 ω-6	9,91a ± 0,15	10,21a ± 0,33	11,69a ± 0,29
cis-8,11,14-cis-8,11,14-Eicosatrienoic acid C20:3 ω-6	3,90a ± 0,17	4,45a ± 0,15	4,60a ± 0,14
cis-5,8,11,14-cis-5,8,11,14-Eicosatetraenoic acid C20:4 ω-6	3,71a ± 0,05	4,97b ± 0,11	4,37b ± 0,15
Total ω6	**33,41**	**37,42**	**39,39**
cis-5,8,11,14,17-Eicosapentaenoic acid C20:5 ω-3	0,74a ± 0,11	0,83a ± 0,05	0,88a ± 0,01
cis-4,7,10,13,16,19-Docosahexaenoic acid C20:6 ω-3	1,95a ± 0,16	2,18a ± 0,02	2,30a ± 0,05
Total ω3	**2,69**	**3,02**	**3,18**
Ratio Sum ω6/Sum ω3	12,42	12,39	12,39
Total PUFA	**36,10**	**40,44**	**42,56**

Means in the same row with different superscripts in the lowercase letter are statistically significantly different ($p < 0.05$).
* Expressed as a percentage of the total fatty acids.

Among the saturated fatty acids in *Helix aspersa maxima*, palmitic acid (C16:0) and stearic acid (C18:0) are predominant, with their lowest levels found in high pressure-cooked samples. The total saturated fatty acid content is highest in sous-vide processed meat (37.71%). These results indicate a significant share of saturated fatty acids in the composition of *Helix aspersa maxima*, which should be taken into account when assessing the nutritional value of this product and its potential health implications.

The PUFA/SFA ratio was 0.96 for sous-vide processing, 1.28 for boiling under atmospheric pressure, and 1.52 for high-pressure boiling. These results suggest that pressure cooking, under the examined thermal conditions, does not lead to increased saturation of fatty acids. In fact, this method yields the most favorable fatty acid profile in terms of nutritional quality, as a higher PUFA/SFA ratio is associated with improved cardiovascular health outcomes.

Szkucik et al. explored the fatty acid profiles of snails, noting a polyunsaturated fatty acid (PUFA) to saturated fatty acid (SFA) ratio of 0.68, suggesting a favorable fatty acid profile conducive to health [15]. The authors found that thermal processing of snail meat led to an overall increase in the levels of all identified saturated fatty acids (SFA), a reduction in polyunsaturated fatty acids (PUFA), and an elevation in the concentrations of monounsaturated fatty acids (MUFA), specifically oleic (C18:1).

Karpińska-Tymoszczyk et al. observed that high-temperature cooking can decrease the content of polyunsaturated fatty acids [19]. In the present study, the applied technological parameters of time and temperature did not lead to a decrease in PUFA levels, indicating their suitability for application in culinary practice.

4 Conclusion

The choice of thermal processing method exerts a strong influence on the nutritional composition of the product. Sous vide cooking consistently demonstrated superior preservation of nutrients, including moisture, proteins, fats, minerals, and carbohydrates. Boiling at atmospheric pressure led to the greatest nutrient losses, particularly in terms of minerals and proteins, whereas high-pressure boiling occupied an intermediate position: while it accelerated cooking, it still caused substantial degradation of some components.

The type of thermal treatment, within the studied parameters, have a substantial impact on the overall chemical composition of snail meat. It is likely that snail meat has a high water content and a stable protein structure that remains largely unaffected within the applied temperature range (up to 121 °C). The absence of significant fat fractions in snail meat reduces the risk of oxidative or thermodestructive processes during heat treatment, and the content of PUFA and MUFA remains high.

Although studies show impact of the type of heat treatment on the chemical composition, sous vide remains a preferred culinary method due to its ability to preserve texture, juiciness, and sensory quality of meat. Additionally, the precise temperature control and vacuum packaging used in sous vide extend shelf life by reducing microbial growth and oxidation, making it advantageous for both culinary and storage purposes.

More research is required to optimize thermal processes and explore innovative alternatives that can preserve or enhance the inherent nutritional value of edible snails and similar food items.

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