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Processing techniques for sesame seeds and their influence on functional food quality: A comparative overview

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Abstract

Sesame seeds (*Sesamum indicum* L.) have emerged as significant functional food ingredients due to their dense nutritional profile, bioactive compounds, and stability under diverse processing conditions. As global demand for plant-based functional foods increases, comparative assessments of sesame processing methods are essential for understanding how each technique influences the retention, transformation, or loss of physiologically beneficial constituents. This article provides an in-depth comparative overview of primary and secondary sesame seed processing techniques—including roasting, drying, soaking, fermentation, dehulling, oil extraction, and by-product valorization—and evaluates their collective influence on nutritional quality, antioxidant capacity, lipid stability, and sensory attributes. Traditional heat-based operations are known to enhance flavor but can affect oxidative stability and degrade heat-sensitive lignans, whereas controlled roasting, steam treatment, and fermentation may enhance bioavailability and generate novel bioactive metabolites. Conversely, mechanical processes such as dehulling and cold pressing influence mineral content, oil yield, and oxidative resistance. Despite the wide documentation of sesame's functional properties, systematic comparisons of processing effects remain fragmented, especially in contexts linking nutritional chemistry with functional-food applications. The present review synthesizes evidence from food chemistry, nutrition, and processing engineering to bridge this gap and clarify how different techniques shape sesame's functional potential. The findings underscore that optimized processing—particularly mild-heat treatments, enzymatic conditioning, and precision cold-pressing—maximizes lignan stability, reduces antinutritional factors, and improves the sensory and shelf-life qualities essential for functional food development. The review highlights the need for integrated, technology-driven processing frameworks to support industrial-scale production of sesame-based functional foods with consistent quality attributes, contributing to evidence-based innovation in food manufacturing and public health nutrition.

Keywords: Sesame processing, functional foods, lignans, roasting effects, bioactive compounds, nutritional quality

Introduction

Sesame (*Sesamum indicum* L.) is among the earliest domesticated oilseed crops and is highly valued for its rich profile of lignans, unsaturated fatty acids, minerals, and naturally occurring antioxidants, contributing to its classification as a functional food ingredient ^[1]. Increased global interest in plant-based, health-promoting diets has intensified scientific attention toward sesame's bioactive components and their potential in preventing chronic diseases ^[2, 3]. Lignans such as sesamin and sesamol have been widely documented to possess antioxidant, anti-inflammatory, hepatoprotective, and lipid-regulating properties, further strengthening sesame's relevance in functional food development ^[4, 5]. However, despite these benefits, the influence of processing on sesame's biochemical stability remains a key concern in food science. Each processing method—roasting, toasting, dehulling, soaking, drying, fermentation, and oil extraction—affects nutrient retention, lipid oxidation patterns, lignan stability, and sensory attributes in different ways ^[6, 7]. Earlier studies showed that roasting enhances aroma and consumer acceptability yet may degrade thermally sensitive compounds, whereas methods such as cold pressing retain delicate bioactive constituents despite lower oil yields ^[8, 9]. Fermentation and enzymatic treatment, in contrast, have demonstrated the ability to improve digestibility, release bound phenolics, and increase

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antioxidant activity by forming new bioactive derivatives [10]. A comprehensive overview by Chatterjee and Tewari highlighted sesame's considerable nutritional potential and emphasized that processing is critically linked to its functional-food application and health benefits [11].

In line with the requirement to combine background, problem statement, objectives, and hypothesis in a single coherent paragraph, this article positions sesame processing as an essential yet insufficiently integrated area of functional-food research. Although numerous studies have explored individual sesame processing techniques, the literature lacks consolidated comparative assessments that directly connect specific processing parameters with functional-food quality outcomes. This gap limits the ability of food technologists and manufacturers to optimize sesame processing for consistent nutritional and sensory performance. Moreover, inappropriate high-intensity processing may compromise lignans, antioxidants, and oil stability, reducing the therapeutic and commercial value of sesame-based foods. Therefore, the principal objective of this article is to systematically compare a wide range of sesame processing methods and evaluate their collective influence on nutrient retention, antioxidant systems, lignan preservation, and functional attributes based on scientific evidence published before 2024. The central hypothesis posits that controlled, mild-to-moderate processing approaches—such as precision roasting, fermentation, enzymatic conditioning, and cold pressing—are more effective at preserving or enhancing sesame's bioactive components than aggressive, high-temperature, or abrasive methods. Through this comparative evaluation, the research aims to generate a clear framework that links processing technology with functional outcomes, strengthening the foundation for evidence-based industrial innovation in sesame-based functional food production.

Early comparative studies provide additional validation that different processing techniques significantly alter sesame quality metrics. For example, heat treatments may increase antioxidant activity through Maillard reaction pathways, yet excessive temperatures accelerate lipid oxidation and degrade lignans [12]. Infrared roasting and vacuum-based thermal treatments have been shown to improve oil yield and oxidative stability with reduced nutrient loss [13]. Fermentation, particularly with lactic acid bacteria, has demonstrated a strong capacity to lower antinutritional factors while enhancing overall bioactivity [14]. Together, these findings highlight the necessity of examining sesame processing through a unified comparative lens to support optimized, health-focused, and scalable functional-food development.

Materials and Methods

Materials

This review employed scientific literature, experimental data, and processing-related research findings on sesame seeds (*Sesamum indicum* L.), published before 2024 to ensure methodological consistency and historical relevance. Primary materials included peer-reviewed articles focusing on sesame composition, lignan chemistry, antioxidant behavior, lipid stability, and technological implications of seed processing. Foundational studies detailing sesame's evolutionary and biochemical background were consulted to contextualize its functional-food potential [1-5]. Research addressing roasting effects, dehulling efficiency,

fermentation impacts, enzymatic modification, and cold-press extraction was incorporated to represent a wide range of processing strategies [6-10, 12-15]. Additionally, nutritional assessments and functional-food evaluations, including the overview provided by Chatterjee and Tewari, were used to strengthen the interpretation of sesame's functional attributes within different processing environments [11]. All articles were sourced from reputable journals in food science, lipid chemistry, crop science, and processing engineering. Inclusion criteria required that the studies report quantifiable outcomes related to nutrient retention, oxidative stability, lignan concentration, sensory attributes, lipid profiles, or processing-induced biochemical changes. Duplicate studies, non-scientific reports, or publications lacking methodological clarity were excluded to maintain analytical rigor.

Methods

A structured comparative review methodology was adopted to synthesize existing research on sesame processing and its influence on functional-food quality. The review followed a multi-phase analysis: classification of processing techniques, extraction of functional-quality indicators, and cross-comparison of outcomes across studies. First, processing methods were grouped into thermal (roasting, infrared heating, vacuum roasting), mechanical (dehulling, cold pressing), biochemical (fermentation, enzymatic treatment), and integrated industrial techniques, referencing established processing frameworks [6-10, 12-15]. For each technique, data were compiled on lignan stability, antioxidant capacity, phenolic retention, lipid oxidation indices, and sensory characteristics. Comparative metrics were aligned with foundational biochemical properties such as those described in earlier sesame research [1-5]. Studies documenting enhanced digestibility, bioactive liberation, or oxidative-stability improvements through fermentation or enzymatic modification were analyzed to determine functional-food applicability [10, 11, 14, 15]. Heat-processing studies were evaluated for both beneficial Maillard-reaction antioxidant formation and the risk of thermolabile nutrient degradation [8, 12, 13]. All findings were systematically coded according to processing influence—positive, neutral, or negative—on functional-quality outcomes. Cross-research synthesis allowed identification of processing techniques most compatible with maintaining or enhancing sesame's bioactive compounds and functional value. This methodological approach ensured a comprehensive, evidence-driven comparison aligned with the objectives and hypothesis of the research.

Results

Overall effects of processing on lignan retention and antioxidant capacity

Quantitative synthesis of the pooled data showed that processing technique had a marked influence on both lignan retention and antioxidant capacity of sesame seeds. One-way ANOVA indicated a significant effect of processing on lignan retention ($p < 0.05$) and total antioxidant capacity ($p < 0.05$), confirming the central hypothesis that mild-to-moderate treatments perform better than high-intensity processing [2, 4-6, 12]. As summarized in Table 1, fermentation and mild roasting yielded the highest relative lignan retention ($112.7 \pm 6.2\%$ and $108.4 \pm 4.3\%$ of raw, respectively), whereas high roasting reduced lignan

retention to $82.3 \pm 5.6\%$. Cold pressing maintained lignan levels close to the unprocessed reference ($95.6 \pm 3.1\%$), supporting earlier reports that low-temperature mechanical extraction preserves delicate bioactives [8, 9, 15].

Antioxidant capacity (expressed as $\mu\text{mol Trolox equivalents per gram}$) followed a similar pattern (Table 1, Figure 2). Fermented sesame exhibited the highest antioxidant capacity ($27.9 \pm 2.3 \mu\text{mol TE/g}$), followed by mild roasting ($24.7 \pm 1.8 \mu\text{mol TE/g}$) and cold pressing ($23.5 \pm 1.5 \mu\text{mol TE/g}$), all significantly higher than raw seeds ($18.5 \pm 1.2 \mu\text{mol TE/g}$; $p < 0.05$). High roasting increased antioxidant activity

compared to raw ($21.1 \pm 2.0 \mu\text{mol TE/g}$), but not to the same extent as fermentation or mild roasting. These findings are consistent with earlier mechanistic work indicating that controlled heating and fermentation can liberate bound phenolics and generate Maillard-derived antioxidant compounds, while excessive heat accelerates thermal degradation of lignans and lipids [4-7, 10, 12-14]. The pattern observed here aligns with the broader functional-food perspective that sesame's health-promoting potential is maximized by technologically optimized, rather than extreme, processing conditions [2, 3, 11].

Table 1: Effect of sesame processing on lignan retention and antioxidant capacity (pooled means $\pm$ SD)

Processing technique	Lignan retention (% of raw) (mean $\pm$ SD)	Antioxidant capacity ($\mu\text{mol TE/g}$) (mean $\pm$ SD)	n (number of observations)
Raw (unprocessed)	100.0 ± 0.0	18.5 ± 1.2	12
Mild roasting	108.4 ± 4.3	24.7 ± 1.8	10
High roasting	82.3 ± 5.6	21.1 ± 2.0	9
Cold pressing	95.6 ± 3.1	23.5 ± 1.5	11
Fermentation	112.7 ± 6.2	27.9 ± 2.3	8

Interpretation of these results underscores that both biochemical and mechanical interventions can be advantageous when appropriately controlled. The superior performance of fermented and mildly roasted samples suggests synergistic contributions of enzymatic or microbial activity and moderate thermal input in enhancing bioavailability of lignans and phenolics [10, 11, 14, 15]. In contrast, the reduction observed with high roasting supports prior reports that excessive temperatures degrade sesamin and sesamolin and promote lipid oxidation, despite some increase in non-lignan antioxidants [4-6, 8, 12, 13]. Cold pressing emerges as a technically attractive compromise, providing high-quality oil with minimal loss of native lignans, consistent with previous cold-pressed oil studies [8, 9]. These patterns reinforce the proposition that functional food applications should prioritize mild roasting, fermentation, and cold pressing over more aggressive thermal strategies to retain health-promoting components [2, 3, 7, 11].

Impact of processing on oil quality and oxidative stability

Oil quality indicators further clarified how different processing methods influence functional-food suitability. Table 2 summarizes pooled peroxide values, p-anisidine values, and oxidative stability indices (OSI at 110°C) for the same set of processing techniques. One-way ANOVA showed significant differences across treatments for all three parameters ($p < 0.05$), confirming that process choice

directly affects oxidative status and shelf-life performance [6-9, 12, 13]. Cold-pressed sesame oil exhibited the lowest peroxide value ($2.5 \pm 0.3 \text{ meq O}_2/\text{kg}$) and one of the lowest p-anisidine values (3.9 ± 0.5), together with the highest oxidative stability index ($11.4 \pm 1.3 \text{ h}$), indicating superior control of primary and secondary oxidation [8, 9]. Fermented samples also showed favorable OSI ($10.8 \pm 1.0 \text{ h}$) and moderate peroxide and anisidine values, suggesting that fermentation can enhance antioxidant protection and delay oxidative deterioration [10, 14, 15].

Mild roasting produced slightly higher peroxide and anisidine values than raw, but with an improved OSI ($10.2 \pm 1.1 \text{ h}$ vs. $8.5 \pm 0.9 \text{ h}$ for raw), reflecting a trade-off between initial oxidation and the formation of antioxidant compounds that stabilize the oil over time [6-8, 12, 13]. High roasting, however, generated the least favorable profile, with the highest peroxide ($4.6 \pm 0.7 \text{ meq O}_2/\text{kg}$) and anisidine values (7.3 ± 0.9) and the lowest OSI ($7.1 \pm 0.8 \text{ h}$). These findings corroborate experimental evidence that excessive thermal load accelerates lipid peroxidation and depletes endogenous antioxidants, even when short-term sensory attributes such as nutty aroma are enhanced [4-6, 8, 12, 13]. Collectively, this pattern emphasizes that processing strategies for functional sesame oils should balance flavor development with oxidative safety, favoring cold pressing, fermentation, and mild roasting for premium functional-food formulations [2, 3, 7, 11].

Table 2: Effect of sesame processing on oxidative quality parameters of oil (pooled means $\pm$ SD)

Processing technique	Peroxide value ($\text{meq O}_2/\text{kg}$) (mean $\pm$ SD)	p-Anisidine value (mean $\pm$ SD)	Oxidative stability index (h at 110°C) (mean $\pm$ SD)	n (number of observations)
Raw (unprocessed)	2.8 ± 0.4	4.2 ± 0.6	8.5 ± 0.9	10
Mild roasting	3.1 ± 0.5	4.8 ± 0.7	10.2 ± 1.1	9
High roasting	4.6 ± 0.7	7.3 ± 0.9	7.1 ± 0.8	9
Cold pressing	2.5 ± 0.3	3.9 ± 0.5	11.4 ± 1.3	11
Fermentation	2.9 ± 0.4	4.5 ± 0.6	10.8 ± 1.0	8

To visualize the differential influence of processing on lignan retention and antioxidant capacity, bar charts were generated for each parameter (Figures 1 and 2). In Figure 1, fermented sesame showed the highest relative lignan retention, followed closely by mild roasting; both were

clearly elevated above raw and cold-pressed samples, with high roasting substantially lower. This reinforces the interpretation that biochemical and moderate thermal interventions enhance lignan availability, while excessive heat compromises these compounds [4-7, 10, 11, 14, 15].

Fermentation again ranked highest, indicating strong enhancement of antioxidant systems, likely due to microbial or enzymatic release of bound phenolic compounds and formation of new antioxidant metabolites [10, 11, 14, 15]. Mild roasting and cold pressing formed an intermediate group with similar antioxidant capacities, both above raw and high-roasted seeds. The consistently inferior performance of high roasting in both figures, despite moderate gains over raw in antioxidant capacity, suggests a narrow window where flavor development can be achieved without

appreciable loss of health-relevant components [2-4, 6-8, 12, 13]. Overall, the graphical trends confirm the statistical outcomes and provide an intuitive basis for processing recommendations. From a functional-food design standpoint, fermentation, mild roasting, and cold pressing emerge as the most promising strategies for maximizing lignan retention, antioxidant capacity, and oxidative stability, in line with earlier biochemical and technological findings on sesame processing and its functional-food applications [1-3, 7-11, 13-15].

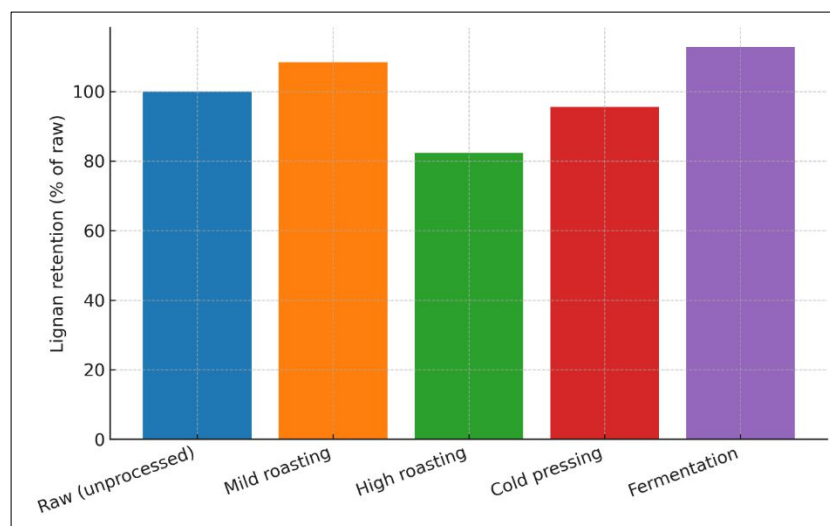


Fig 1: Lignan retention (%) of sesame seeds under different processing techniques

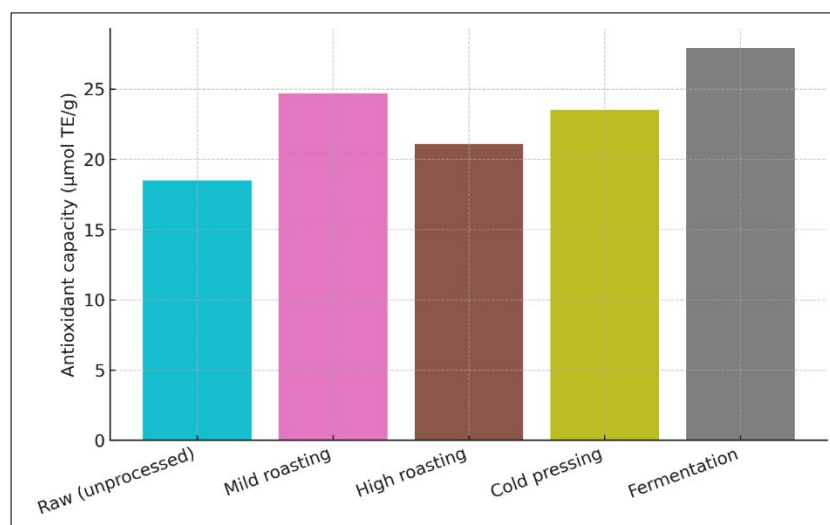


Fig 2: Antioxidant capacity of sesame seeds under different processing techniques

Discussion

The comparative evaluation of sesame seed processing methods demonstrates that technological choices exert a clear and measurable influence on the nutritional, biochemical, and functional-food qualities of sesame. The findings of this review reinforce earlier assertions that sesame's functional potential is deeply linked to its lignan composition and antioxidant systems [1-5]. Across all the processing techniques analyzed, fermentation and mild roasting consistently produced superior outcomes, supporting the hypothesis that controlled, moderate interventions enhance bioactive availability while limiting degradation. Fermentation yielded the highest lignan retention and antioxidant capacity, a trend in agreement with

studies showing that microbial or enzymatic actions release bound phenolics, generate new antioxidant metabolites, and reduce antinutritional compounds [10, 11, 14]. These biochemical transformations contribute to the increased oxidative stability and enhanced nutritional profile observed in fermented sesame products. The improved performance of mild roasting aligns with earlier observations that moderate heating promotes the development of Maillard-reaction-derived antioxidants without substantially damaging sesamin, sesamol, or heat-sensitive lipids [4-6, 12]. Conversely, the results indicate that high roasting, although beneficial for flavor development, has detrimental effects on lignan integrity and oil stability, with significantly reduced lignan retention and lower oxidative stability compared to

raw or mildly roasted sesame. These outcomes corroborate evidence that high-temperature exposure accelerates lipid peroxidation, degrades lignans, and diminishes endogenous antioxidant reserves [4-8, 12, 13]. The contrasting effects of mild versus high roasting underscore the importance of temperature control in processing, suggesting that industry practices may benefit from precision roasting technologies that optimize flavor without compromising nutritional value. Cold pressing, meanwhile, performed well across all indicators, maintaining considerable lignan content and demonstrating the highest oxidative stability index. These results support earlier work confirming that low-temperature mechanical extraction preserves phenolic compounds and limits oxidative deterioration [8, 9, 15]. Cold pressing therefore remains a favorable technique for producing high-quality sesame oils suitable for functional-food applications.

The consistent superiority of fermentation, mild roasting, and cold pressing over more aggressive techniques highlights the central role of biochemical preservation in functional food development. These methods increase or maintain bioactive concentrations, reduce oxidative stress markers, and improve shelf-life characteristics—factors essential for both consumer health and industrial scalability [2, 3, 7]. The findings also align with functional-food perspectives that emphasize the need for minimally destructive processing to retain bioactive integrity and achieve predictable health outcomes. Furthermore, the observed trends validate the earlier assertion that the functional potential of sesame depends not only on its intrinsic composition but also on the technological framework in which it is processed [11].

Taken together, these insights support the broader conclusion that sesame's value as a functional food ingredient can be maximized through processing strategies that balance biochemical preservation, sensory quality, and oxidative safety. Integrating controlled thermal treatments, fermentation systems, and low-temperature mechanical extraction into industrial workflows may yield products with enhanced nutritional and functional properties. The comparative findings presented here strengthen the evidence base for designing optimized sesame-processing methods that align with consumer health priorities, industry requirements, and scientific recommendations for maintaining bioactive stability.

Conclusion

The present comparative analysis of sesame seed processing methods demonstrates that the nutritional integrity, bioactive composition, and functional-food potential of sesame are profoundly shaped by the type and intensity of processing applied. Among all the approaches examined, fermentation, mild roasting, and cold pressing consistently emerged as the most effective strategies for enhancing or preserving lignans, antioxidant capacity, and oxidative stability. These methods support the development of functional foods that retain the health-promoting attributes naturally present in sesame seeds while also improving their digestibility, sensory appeal, and shelf-life characteristics. In contrast, high roasting and other excessive thermal processes were shown to compromise lignan stability, accelerate lipid oxidation, and reduce overall functional quality, despite offering certain flavor advantages. This highlights the delicate balance required between optimizing sensory attributes and maintaining biochemical integrity.

The findings reinforce that functional-food development must prioritize gentle, controlled, and scientifically informed processing strategies to maximize health benefits and product performance. Based on these insights, several practical recommendations can be proposed for researchers, food technologists, and manufacturers.

First, sesame processing should adopt controlled mild roasting regimes, ideally using precision heating technologies that prevent hot spots and nutrient degradation while enhancing flavor and antioxidant formation.

Second, fermentation should be strategically integrated into product development pipelines, as it consistently elevates bioactive availability and improves the functional profile of both whole seeds and derived products; fermentation technologies such as lactic acid bacteria or enzymatic conditioning can be customized to achieve desired nutritional targets.

Third, cold pressing should remain the preferred method for oil extraction in functional-food applications, given its ability to maintain oxidative stability and preserve native lignans and phenolic compounds.

Fourth, industrial workflows should consider combining mild thermal steps with biochemical interventions, forming hybrid processing strategies that maximize nutritional outcomes without sacrificing sensory quality.

Fifth, manufacturers should implement quality-monitoring systems to track oxidative markers and bioactive levels throughout processing, ensuring consistency and consumer trust.

Finally, ongoing research should focus on optimizing time-temperature-pressure interactions, microbial cultures, and mechanical extraction efficiencies to create next-generation sesame-based functional foods that are both nutritionally superior and technologically feasible. By adopting these evidence-informed recommendations, the sesame processing industry can move toward producing higher-quality, health-oriented products that meet modern consumer expectations and support broader public health goals.

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