Pertanika J. Trop. Agric. Sci. 49 (1): 1 - 24 (2026)

PERTANIKA JOURNALS

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Review Article

A Systematic Review of Seed Oils: From Extraction to Health-boosting Food Solutions

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ABSTRACT

This systematic review presents recent research on seed oils, with an emphasis on extraction processes, health-promoting properties, and potential applications in food product development. As interest grows in sustainable and health-conscious food alternatives, seed oils have gained attention for their usefulness and nutritional value. However, there is a lack of up-to-date and systematic reviews that cover the entire scope of seed oil research, from extraction techniques to their nutritional and functional roles. To fill this gap, a systematic search was performed using the Scopus and ScienceDirect databases, with articles published between 2023 and 2025 being prioritised. The PRISMA guidelines guided this systematic review, with the resultant integration of relevant literature. The findings were categorised into three main themes: (1) extraction, characterisation, and functional properties of seed oils; (2) health benefits, nutritional value, and functional applications; and (3) seed oils in food product development and fat replacement. There has been significant improvement in extraction technologies, along with the identification of bioactive compounds present in seed oils, which may provide beneficial health effects. This review emphasises the importance of seed oils in improving food quality and enhancing consumer health. These findings are an important resource for researchers and food industry professionals interested in exploring the broader applications of seed oils in food technology and health-oriented solutions.

Keywords: Extraction, fat, food, replacer, seed oil, substitute

ARTICLE INFO

Article history:
Received: 30 January 2025
Accepted: 10 November 2025
Published: 30 January 2026

DOI: https://doi.org/10.47836/pjtas.49.1.01

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e-ISSN: 2231-8542

INTRODUCTION

The potential of seed oils to improve human health has been extensively studied, especially when they contain a considerable amount of unsaturated fatty acids. It has been found that substituting pumpkin seed oil for saturated fats in the diet can reduce the severity of atherosclerosis and non-alcoholic fatty liver disease. Another benefit to cardiovascular health is the phytochemical content of pumpkin seed oil, which enhances its anti-inflammatory properties (Morrison et al., 2015). Chia seed oil has been used to replace milk fat in ice milk because it is rich in omega-3 fatty acids. This makes the product more nutritious and gives it more antioxidant properties (Basuny et al., 2021). The fatty acid composition of seed oils makes them suitable replacements for industrial fats. Ficus sur seed oil contains stearic acid, which is considered a healthier option compared to industrial trans fats, while high stearic sunflower oil has saturated fats that can replace hydrogenated oils and palm oil in various applications (Nwanisobi et al., 2021; Salas et al., 2014).

Seed oils are also valued for their rich content of bioactive compounds. Tocopherols and polyphenols are among the compounds that contribute to the health-promoting properties of seed oils. This bioactive profile supports not only health benefits but also a variety of non-food applications. The diverse range of bioactive compounds found in the seed oils has led to their increasing use in the cosmetic industry and as sustainable alternatives to petroleum-based products (Pachuau et al., 2019). In the cosmetic industry, oils derived from fruit seeds, including raspberry and grape seed oils, are increasingly used due to their beneficial effects on skin health. These oils help slow down the aging process and relieve stress-related skin conditions (Kaseke et al., 2020). Seed oils are known to improve skin conditions and are used in cosmetic formulations due to their moisturising and protective properties (Sumara et al., 2023). The oils extracted from sunflower, sesame, canola, and flaxseed seeds contain high amounts of essential fatty acids together with antioxidants and bioactive compounds. The high polyunsaturated fat content of seed oils, particularly omega-3 and omega-6 fatty acids, sustains cellular structure and promotes overall health (Quintero-Angel et al., 2023; Tiencheu et al., 2021).

Recent studies have highlighted the health-promoting properties of specific seed oils. Some examples include omega-3 rich flaxseed oil and its anti-inflammatory properties (Romanić et al., 2021) or pumpkin seed oil and its ability to enhance urinary functions and prostate health (Kang et al., 2021). Sesame and chia seed oils are rich in polyunsaturated fatty acids (PUFA), which have been shown to improve blood lipid profiles and lower cholesterol levels, thus reducing the risk of heart disease (Morrison et al., 2015; Parker et al., 2018; Sohouli et al., 2022). The presence of bioactive compounds such as tocopherols and carotenoids contributes to the antioxidant and anti-inflammatory effects of seed oils, which help mitigate chronic inflammation and oxidative stress, both of which are commonly linked to various diseases (Šamec et al., 2022; Sumara et al., 2023). Pumpkin seed oil has been shown to help regulate blood glucose, which is important for managing diabetes (Morrison et al., 2015; Sohouli et al., 2022). Kiwifruit seed oil has also demonstrated potential in weight management by regulating inflammation, enhancing thermogenesis, and improving gut microbiota, which are essential factors in obesity management (Qu et al., 2019). Prickly pear seed oil is valued for their antioxidant and anti-inflammatory properties, which help protect against diseases related to oxidative stress and inflammation (Al-Naqeb et al., 2021).

As global awareness about the environmental impact of conventional fat sources rises, seed oils are emerging as sustainable options. For example, researchers have studied the rheology of fat blends containing rapeseed and sunflower oils to develop practical alternatives to palm oil in food applications (Kovács et al., 2024). This effort highlights the potential of seed oils to contribute to more sustainable and environmentally friendly practices in the food industry and beyond. Seed oils also show potential in the energy sector. Tomato seed oil has been identified as a good candidate for alternative fuel due to its favourable properties such as low volatility, low sulfur content, and high viscosity, making it suitable for use in diesel engines (Giannelos et al., 2005). The high oil yield and effective conversion of mandarin seed oil into biodiesel, which shows comparable properties to regular diesel fuels, have made it a promising alternative fuel (Azad, 2017).

This systematic review aims to provide a comprehensive overview of seed oils from their composition and extraction methods to the usage in health-boosting foods. The information will also provide insights on the health benefits offered by different seed oils ranging from disease prevention to overall wellness. It will highlight unresolved issues and propose future research directions to maximise the potential of seed oils in functional food development.

In this systematic review, the PICO framework was applied to formulate the research questions (Wurschi et al., 2025). This structured approach helps outline focussed research questions and ensures a systematic evaluation of existing literature. The four components of PICO are defined as follows:

1. Population (P): This is the population or context of interest, which in this study includes the use of seed oils in food systems and functional food development.
2. Intervention (I): This involves the application of seed oils, either through different extraction techniques or as fat substitutes in food products.
3. Comparison (C): This includes conventional fats or oils, such as animal fats and palm oil, used as the standard or baseline for comparison.
4. Outcome (O): This refers to the nutritional, functional, technological, or health-related effects of using seed oils.

Based on this framework, the following research questions were outlined:

1. How do different seed oil extraction methods affect the functional properties and quality of seed oils used in food systems?
2. What are the health benefits of incorporating seed oils in human diets compared to conventional fat sources?
3. How can seed oils replace animal fats or palm oil in food products while maintaining desirable nutritional and sensory qualities?

MATERIALS AND METHODS

An established framework that is frequently used for conducting systematic literature review (SLR) is the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. It ensures transparency, completeness, and consistency throughout the entire process (Page et al., 2021). These guidelines provide clear instructions on how to systematically identify, screen, and choose studies to be included in a review. The method also highlights the significance of including randomised studies, which are essential in reducing bias and providing stronger evidence. Scopus and ScienceDirect were selected for this analysis because of their reliability and broad coverage.

The selection and screening process of the articles included in this review is summarised in Figure 1. The PRISMA approach was structured into four primary phases: identification, screening, eligibility, and data abstraction. In the identification stage, relevant studies were located through database searches. The screening part requires assessing these studies against predetermined criteria in order to exclude studies that were either inappropriate or of insufficient quality. In the eligibility step, the remaining studies were thoroughly evaluated to ensure they met the inclusion requirements. Lastly, the data abstraction phase includes extracting and synthesising information from the selected research, which is an important step for drawing relevant and valid conclusions. This systematic process guarantees that the review was performed with high accuracy, which results in reliable findings that can inform future studies and practice.

Identification

In the identification stage of the SLR, relevant records were obtained from Scopus and ScienceDirect by performing keyword-based searches using “seed oil” and “fat substitute” terms. These terms were employed to construct detailed search strings, which were then used to query both databases, as outlined in Table 1. Filters were applied to restrict the search to academic journal articles and conference proceedings published within recent years, ensuring the retrieved literature was both up-to-date and pertinent. This process resulted in a total of 960 records, with 921 records from Scopus and 39 from ScienceDirect.

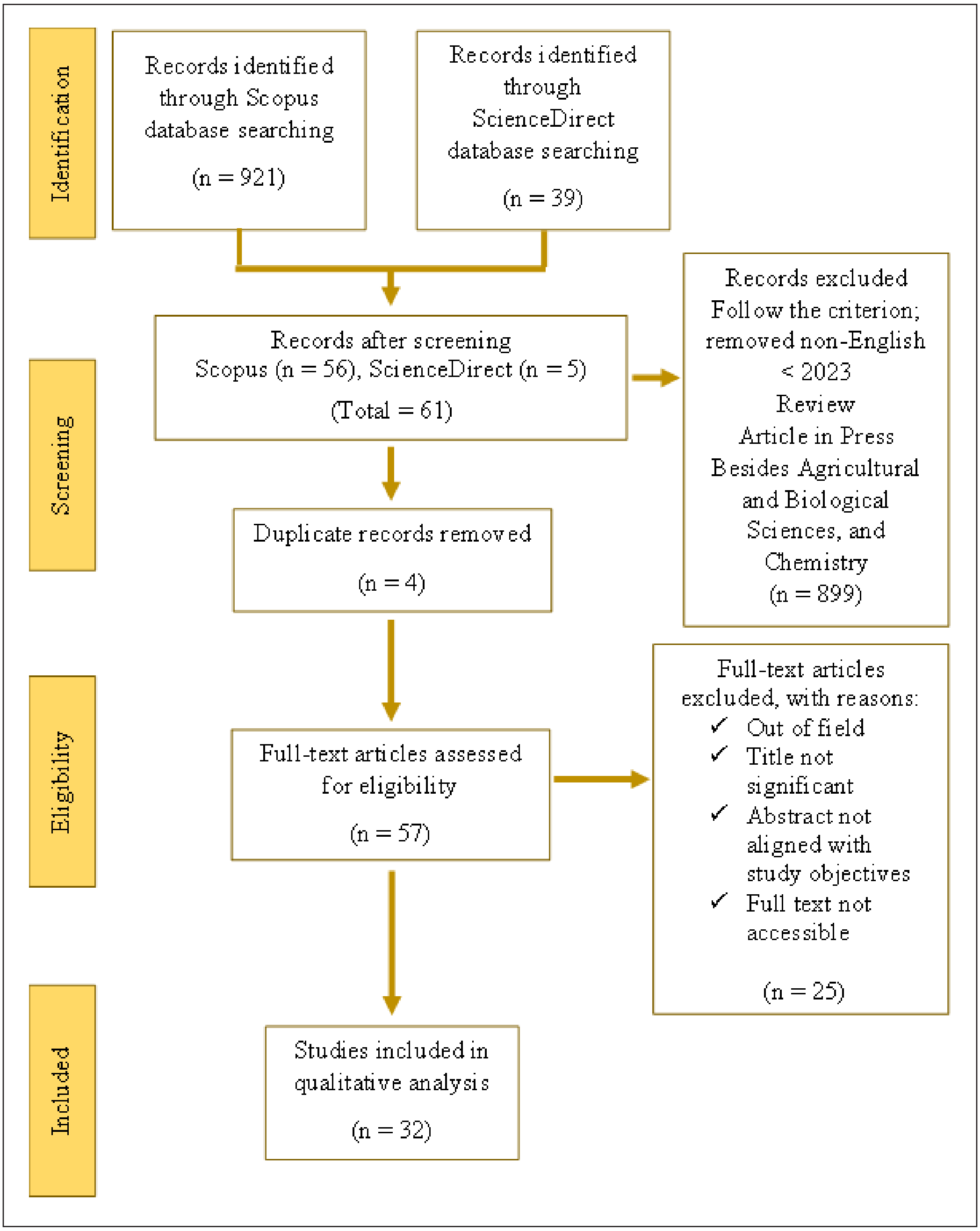

Figure 1. Flow diagramme of the proposed searching study (Moher et al., 2009)

Table 1
The search string

Scopus	ScienceDirect
TITLE-ABS-KEY ("seed oil" AND fat AND (substitute OR alternat* OR replace*)) AND (LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "CHEM")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025)) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English")) Date of Access: December 2024	"Seed oil" AND fat AND (substitute OR alternat OR replace) Date of Access: December 2024

Screening

In the screening stage, records retrieved during the identification phase were subjected to screening based on predefined inclusion and exclusion criteria (Table 2). Non-English articles, those published before 2023, review articles, and articles in press were excluded, along with records from journals outside the fields of Agricultural and Biological Sciences, and Chemistry. A total of 899 records were excluded following these criteria. Titles and abstracts of the remaining records were examined, and irrelevant articles were excluded. This process resulted in 56 records from Scopus and 5 from ScienceDirect, resulting in a total of 61 articles. Duplicate records across the two databases were removed, with 4 duplicates eliminated. The final 61 records were then prepared for further quality assessment and detailed analysis in subsequent stages of the SLR.

Table 2
The chosen criteria for searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2023 – 2025	< 2023
Literature type	Journal (Article)	Review
Publication Stage	Final	Article in Press
Subject	Agricultural and Biological Sciences; Chemistry	Besides Agricultural and Biological Sciences, and Chemistry

Eligibility

In the third step of the SLR process, eligibility criteria were applied to 57 articles, resulting in the exclusion of 25 studies. These exclusions were based on various reasons such as irrelevance to the field, non-significant titles, abstracts not aligned with the study objectives, lack of full text access, or being out of scope. After applying these exclusion criteria, the remaining 32 studies were considered eligible and included in the qualitative analysis

(Table 3). This step ensures that only studies that closely align with the research objectives and meet the predefined quality standards are considered for in-depth analysis.

Table 3
Details of primary studies database

No.	Study	Journal	Scopus	ScienceDirect
1	Piasecka et al. (2023)	European Food Research and Technology	/	
2	Martínez et al. (2023a)	Foods	/	
3	Martínez et al. (2023b)	Foods	/	
4	Hou et al. (2025)	Food Hydrocolloids	/	/
5	Patil et al. (2024)	Industrial Crops and Products	/	
6	Hamed et al. (2024)	Journal of Food Measurement and Characterisation	/	
7	Li et al. (2024)	Food Chemistry: X	/	
8	Mesquita et al. (2023)	Food Science and Technology (Brazil)	/	
9	Avci et al. (2023)	Foods	/	
10	Momchilova et al. (2023a)	Journal of Central European Agriculture	/	
11	Ni et al. (2024)	Applied Food Research	/	/
12	Albayrak et al. (2023)	Journal of Food Science and Technology	/	
13	Zhang & Li (2024)	Food Production, Processing and Nutrition	/	
14	Pasrija et al. (2024)	Applied Food Research	/	
15	Akinsola et al. (2023)	Journal of Culinary Science and Technology	/	
16	Briceño-Islas et al. (2024)	Food Chemistry	/	
17	Botella-Martínez et al. (2023)	European Food Research and Technology	/	
18	Difonzo et al. (2024)	LWT	/	/
19	Khazaai et al. (2024)	Bioenergy Research	/	
20	Abbas et al. (2023)	International Journal of Food Properties	/	
21	Charoenphun et al. (2024)	Current Applied Science and Technology	/	
22	Joshi et al. (2024)	Journal of Food Measurement and Characterisation	/	
23	Momchilova et al. (2023b)	Food Research	/	
24	Alkabaa et al. (2024)	Foods	/	

Table 3 *(continued)*

No.	Study	Journal	Scopus	ScienceDirect
25	Pojjanapornpun et al. (2023)	Journal of the American Oil Chemists' Society	/	
26	Oba & Yıldırım (2024)	Journal of Food Measurement and Characterisation	/	
27	Yang et al. (2024)	Journal of Oleo Science	/	
28	Tarjuelo et al. (2023b)	Foods	/	
29	Visković et al. (2024) .	Industrial Crops and Products	/	
30	Sepeidnameh et al. (2024)	Current Research in Food Science	/	/
31	Papatzimos et al. (2024)	Foods	/	
32	Tarjuelo et al. (2023a)	Journal of Functional Foods		/

Data Abstraction and Analysis

One of the primary assessment methodologies used in this study was an integrative analysis, which was used to investigate and synthesise multiple research designs, particularly quantitative methods. The main aim of this approach was to identify appropriate themes and subtopics related to the focus of study. The data collection phase was the first stage in theme development. As shown in Figure 1, a detailed review of 32 publications was conducted to extract claims or information related to the themes under investigation. Subsequently, significant studies on seed oils were assessed, with attention given to the methodologies used and the findings produced.

The next step involved collaboration with co-researchers to identify themes based on the findings in the context of this study. A log was kept throughout the data analysis process to document any analyses, challenges, perceptions or reflections that arose during the interpretation of the data. Lastly, the results were compared to identify any discrepancies in the theme development process. If conflicts regarding the concepts arose, these were discussed and solved through collective deliberation among the authors.

QUALITY OF APPRAISAL

The process of assessing the quality of selected primary studies is an essential step in SLR. Following the guidelines provided by Kitchenham (2007), it is crucial not only to choose relevant studies but also to critically evaluate the quality of the research findings and make a quantitative comparison of the studies. In this review, an approach of quality assessment (QA) based on Abouzahra et al. (2020) was adopted. This method consists of six key criteria that serve as the basis for evaluating the quality of the studies included in this review.

The QA was based on a scoring procedure that includes three possible ratings for each criterion: "Yes" (Y) for a score of 1, indicating full satisfaction of the criterion; "Partly" (P) for a score of 0.5, suggesting partial fulfilment with some gaps; and "No" (N) for a score of 0, if the criterion is not met at all. The scoring was conducted by three independent experts who evaluated each study based on the following six QA criteria:

QA1 : Does the study have a clear purpose? The criterion verifies whether the study has a well-defined purpose. A well-defined purpose gives the research a clear direction and guarantees that the scope of the research is well understood.

QA2 : Does the work clearly convey its interest and usefulness? This examines whether the work clearly explains its relevance and potential implications. It is significant that the research makes its relevance clear to emphasise its contribution to the field and beyond.

QA3 : Is the research methodology clearly stated? The focus of this criterion is on evaluating the methodology used in the study. A clear and appropriate methodology is key to getting reliable results and ensuring the reproducibility of the study.

QA4 : Are the approach's concepts explained clearly? This criterion assesses whether the key concepts and theoretical framework of the study are well-defined and explained. Clear definitions are needed to understand the research methodology used.

QA5 : Does the work get measured and compared to other comparable studies? This verifies if the study contextualises its findings in relation to existing scholarly literature. By benchmarking the study against other similar works, the researcher shows how the current study contributes to the existing body of knowledge and addresses gaps or challenges in the field.

QA6 : Are there any clear constraints to the work? This criterion examines whether the research clearly states its restrictions. Recognising and discussing the limitations is critical to understanding the boundaries of the research findings and their generalisability.

Each expert evaluated the study independently, and each of their individual scores for every criterion were then combined to produce a total score for the study. The sum of the scores across all experts determined whether the study is of sufficient quality to proceed in the review process. A study must receive a total score greater than 3.0 to be eligible for inclusion in the next stage. The threshold ensures that only studies scoring an acceptable quality are eligible to proceed with the review process. This improves the validity and reliability of reported findings.

RESULTS AND FINDINGS

Based on the QA, Table 4 presents the performance results of the selected primary studies. The review of 32 articles reveals a generally high standard of research, with some areas excelling and others needing improvement.

Most of the studies showed excellent clarity in defining the purpose of their research (QA1), effectively outlining their objectives and the significance of their work. These articles often highlighted the practical implications of their findings, particularly in the context of food science and oil production. However, there were a few papers that lacked sufficient detail on their specific aims, leaving the reader with some ambiguity regarding the scope of the study.

For the explanation of the relevance and applicability of the research (QA2), most of the studies were successful in clearly demonstrating the relevance and usability of their findings, especially in addressing real-world challenges like food product enhancement or developing sustainable production processes. However, some studies could have better connected their findings to broader industry or social requirements, which would have made the research more compelling and impactful.

In terms of methodology (QA3), most articles performed well, with clear explanations of methods used in their research. This made it easy for readers to understand the adopted approach, particularly for studies on complex processes such as lipid emulsions or enzymatic reactions. However, there were some articles that had some gaps in method descriptions, which could make readers unfamiliar with the methods fail to fully understand the processes used.

Most of the studies also did well in defining the concepts behind their approach (QA4), so that major terms and concepts were explained in detail. This was especially crucial in more technical subjects like fatty acid compositions or seed oil extraction methods. However, some studies could have explained some concepts better, especially for specialized or niche subjects, to provide more clarity to less familiar readers.

Regarding the comparison with other similar work (QA5), most studies were able to position their results within the wider scientific literature by citing previous research. This helped to validate their results and highlighted the novelty of their contributions. However, a few studies missed this opportunity, not fully engaging with past literature, which made it harder to assess how their results fit into the existing body of knowledge.

Finally, reporting of the limitations of the studies (QA6) indicated that most of the studies did mention their limitations but these were usually brief and not elaborated. Common limitations mentioned included sample sizes, methodological constraints, and external factors affecting the outcome. A few studies did not discuss their limitations in detail, which could have led to questions about the robustness and applicability of their findings. A more thorough and transparent discussion of limitations would have enhanced the credibility of these studies.

In summary, while the studies generally performed well, with an average score above 75% and some showing more than 80%, there are clear areas for improvement. Most of the studies adequately defined their purposes, defining concepts, and comparing their findings with existing research. However, more in-depth discussions on study limitations and stronger engagement with prior work could further strengthen the overall quality of future research in this field.

Table 4
Quality assessment of the selected articles

Study	QA1	QA2	QA3	QA4	QA5	QA6	Total Marks	Percentage (%)
Piasecka et al. (2023)	1	1	1	1	1	1	6	100
Martínez et al. (2023a)	1	1	1	1	1	1	6	100
Martínez et al. (2023b)	1	1	1	1	1	1	6	100
Hou et al. (2025)	1	1	1	1	1	0.5	5.5	91.67
Patil et al. (2024)	1	1	1	1	0.5	1	5.5	91.67
Hamed et al. (2024)	1	1	0.5	1	0.5	0	4	66.67
Li et al. (2024)	1	1	1	0.5	0.5	0.5	4.5	75
Mesquita et al. (2023)	1	1	1	1	0	0.5	4.5	75
Avci et al. (2023)	1	1	1	1	1	0.5	5.5	91.67
Momchilova et al. (2023a)	1	0.5	1	1	1	0.5	5	83.33
Ni et al. (2024)	1	1	0.5	1	0.5	0.5	4.5	75
Albayrak et al. (2023)	1	1	0.5	0.5	0.5	1	4.5	75
Zhang & Li (2024)	1	1	1	1	1	0.5	5.5	91.67
Pasrija et al. (2024)	1	1	1	1	0.5	0.5	5	83.33
Akinsola et al. (2023)	1	1	1	1	1	1	6	100
Briceño-Islas et al. (2024)	1	1	1	1	1	0.5	5.5	91.67
Botella-Martínez et al. (2023)	1	1	1	1	1	0.5	5.5	91.67
Difonzo et al. (2024)	1	1	1	1	1	0.5	5.5	91.67
Khazaai et al. (2024)	1	1	1	1	1	0.5	5.5	91.67
Abbas et al. (2023)	1	1	1	1	0.5	1	5.5	91.67
Charoenphun et al. (2024)	1	1	0.5	1	0.5	0.5	4.5	75
Joshi et al. (2024)	1	1	1	1	0.5	1	5.5	91.67
Momchilova et al. (2023b)	1	1	1	0.5	1	0.5	5	83.33
Alkabaa et al. (2024)	1	1	1	1	0.5	1	5.5	91.67
Pojjanapornpun et al. (2023)	1	1	1	1	1	1	6	100
Oba & Yıldırım (2024)	1	1	1	1	0.5	1	5.5	91.67

Table 4 *(continued)*

Study	QA1	QA2	QA3	QA4	QA5	QA6	Total Marks	Percentage (%)
Yang et al. (2024)	1	1	1	1	1	1	6	100
Tarjuelo et al. (2023b)	1	1	1	0.5	1	0.5	5	83.33
Visković et al. (2024)	1	1	1	1	0.5	0.5	5	83.33
Sepeidnameh et al. (2024)	1	1	1	1	0.5	1	5.5	91.67
Papatzimos et al. (2024)	1	1	1	1	1	0.5	5.5	91.67
Tarjuelo et al. (2023a)	1	1	1	1	1	0.5	5.5	91.67

The themes generated were refined to ensure consistency. The process of selection and analysis was carried out by the author and co-authors to verify the validity of the issues identified. An expert review phase was incorporated to confirm the clarity, relevance, and appropriateness of each subtheme, thereby establishing domain validity. Any discrepancies or disagreements in the development of the themes were discussed and resolved among the authors. If inconsistencies in the themes arose, they were addressed collectively. In the final step, the themes were adjusted to maintain consistency. The validity of the issues was further evaluated by two experts, one specialising in chemistry and the other in food technology. This expert review phase played a critical role in confirming the clarity, importance, and adequacy of each subtheme, thereby establishing its domain validity. Any necessary revisions were made based on expert feedback and comments, allowing the themes to be fine-tuned accordingly.

Extraction, Characterisation, and Functional Properties of Seed Oils

This section compiles insights from 13 studies that explored various extraction methods, characterisation techniques, and the functional properties of seed oils. Numerous methods have been researched to enhance the yield of oil from seeds, with each method having its advantages and challenges. Ultrasound-assisted extraction (UAE) has emerged as a promising technique, as demonstrated by Piasecka et al. (2023), who utilised it to extract oil from cranberry seeds. This method, compared to conventional extraction processes, offers a more environmentally friendly approach, minimising harmful impacts. In the study, UAE parameters such as amplitude and extraction time were optimised to achieve the highest oil yield with an improved quality. The oil extracted under optimal conditions exhibited a unique fatty acid profile, with a higher presence of oleic and α-linolenic acids, and demonstrated improved oxidative stability, which could benefit the food and cosmetic industries. The findings suggested that ultrasound-assisted processes had the ability to reduce environmental impacts without sacrificing oil quality.

Innovative methods have also explored seed oils as functional ingredients. Hou et al. (2025) explored the role of pea protein/carrageenan emulsion gels as solid fat substitutes, incorporating various seed oils such as sunflower seed oil and palm stearin. These gels were evaluated for their texture, crystallisation, and sensory properties, providing insight into their potential use in food products like sausages. The study found that emulsion gels made with specific oil phases, particularly palm stearin, had comparable textural properties and crystallisation behaviour to those of animal fats. This opens up the possibility of developing healthier, plant-based fat substitutes that mimic the functional properties of traditional animal fats. Hence, it offers a sustainable and nutritious option for reduced-fat food products.

The versatility of seed oils extends beyond food products, with applications in industrial coatings also being conducted. Patil et al. (2024) focussed on the use of *Madhuca indica* (mahua) seed oil in the synthesis of polyurethane-based anticorrosive coatings. These coatings, derived from renewable sources, exhibited excellent thermal stability and corrosion resistance, which suggests seed oils can replace petroleum-derived materials in industrial applications. The study suggests the suitability of seed oils for the production of green and high-performance materials, which is consistent with growing demand for sustainable and renewable alternatives in various industries.

The potential use of seed oils as functional food additives has been also investigated based on their bioactive components, such as antioxidant and antimicrobial activity. Mesquita et al. (2023) studied papaya seed oil, which is a by-product of fruit processing, to assess the nutritional and bioactive potential. The oil was shown to be rich in oleic acid, a monounsaturated fatty acid, and exhibited high antioxidant activity. However, its antimicrobial properties were less pronounced. This finding is consistent with the broader trend of using waste by-products to produce functional ingredients with beneficial health effects that assist in mitigating agro-industrial waste.

Another significant example is the work by Ni et al. (2024), which involved the use of *Lycium barbarum* seed oil-based oleogels for chocolate production. The inclusion of oleogels in chocolate formulations offers a promising strategy for reducing saturated fat content while retaining the stability and texture of the product. The study proved that *Lycium barbarum* seed oil oleogels significantly improved the storage stability of chocolate by reducing the occurrence of undesirable changes such as surface frosting and the overall shelf life. Such innovations illustrate the potential of seed oils in the production of healthier and more stable food products.

In addition to these developments, significant advances have been made in optimising oil extraction processes for various seed types. Khazaai et al. (2024) applied an Adaptive Neuro-Fuzzy Inference System (ANFIS) model to predict the oil extraction yield from rubber seeds. The study identified key factors such as moisture content and particle size that influenced the extraction efficiency and hence is important information for the development of extraction procedures. The percentage oil yield from rubber seeds with a high content of unsaturated fatty acids makes this seed a viable feedstock for biodiesel production, which improves the sustainability of biofuel production further.

The development of novel food formulations using seed oils has also been explored in the context of low-fat mayonnaise production. Alkabaa et al. (2024) used a combination of chia seed oil by-product gum and other stabilising agents to create bigels, which were subsequently used in low-fat mayonnaise formulations. The bigels were shown to be a good fat replacer, being able to mimic the texture and consistency typical of full-fat mayonnaise. This study reflects the growing interest in plant-based ingredients to replace traditional fats as healthier alternatives without compromising sensory properties.

The capability of multilayer emulsions in enhancing the stability and oxidative properties of seed oils has been highlighted by Sepeidnameh et al. (2024). By encapsulating grape seed oil in multilayer emulsions, they introduced considerable enhancement in the stability of the oil, which is crucial for its use in food products. The study indicated that increasing the number of layers in the emulsion improved both the physical and oxidative stability of the oil. This makes it a more reliable ingredient for food formulations. This procedure can help reduce the issues due to the inherent instability of certain seed oils and thus enhance their commercial viability.

Health Benefits, Nutritional Value, and Functional Applications of Seed Oils

A total of 10 studies were identified under this theme, which focussed on the nutritional composition, bioactive compounds, and health-promoting effects of seed oils. It has been shown that several oils, such as those from muskmelon, mango, and guava seeds, contain essential fatty acids, polyphenols, and antioxidants, which improve human health (Abbas et al., 2023; Joshi et al., 2024; Pasrija et al., 2024). These oils have been linked to promote may help cardiovascular health by lowering cholesterol levels due to its high linoleic acid content (Pasrija et al., 2024). The high PUFA content of guava seed oil makes it more beneficial than conventional fats in food (Joshi et al., 2024).

Beyond nutrition, seed oils are utilised in food preservation, processing and product development. Seed oils such as those from mango and grape seed oils have been studied for their potential to enhance product quality and prolong shelf life. Mango seed oil, which is rich in palmitic and stearic acids has already been utilised as a substitute for cocoa butter in chocolate. With this substitution, the antioxidant capacity as well as the sensory attributes have improved (Abbas et al., 2023). Similarly, grape seed oil has been used in salad dressings for better oxidative stability and improved sensory qualities, but lower fat content of the product (Joshi et al., 2024). These examples highlight the functional properties of seed oils in developing healthier and more acceptable food products, which are gaining consumer interest due to their health-promoting effects.

Seed oils also play a significant role in non-food industries. A valued ingredient in nutraceutical products is chia seed meal protein hydrolysates obtained from a by-product of chia oil extraction, which exhibit significant antidiabetic and antioxidant activities (Briceño-Islas et al., 2024). This waste-to-value approach, where seed by-products such as protein hydrolysates are utilised for their bioactive properties, shows the sustainable use of seed oils and their derivatives in creating functional food ingredients (Briceño-Islas et al., 2024; Visković et al., 2024).

The health benefits of seed oils are further emphasised in the context of their bioactive compounds, including polyphenols, antioxidants, and essential fatty acids. For instance, the antioxidant potential of pomegranate and grape seed oils has been shown to preserve the quality of fresh-cut fruits and vegetables (Albayrak et al., 2023). The incorporation of these oils into emulsions for electrospray-coating methods demonstrated improved both sensory qualities and antioxidant activity (Albayrak et al., 2023). These findings suggest that the incorporation of seed oils in food processing improves the shelf life of products while also boosting their nutritional value, making them ideal for health-conscious consumers.

Seed Oils in Food Product Development and Fat Replacement

This section reviews 9 studies that investigated the use of seed oils in food formulations, particularly as fat substitutes in meat and bakery products. The use of seed oils as substitutes for animal fats in food product development is gaining significant attention, particularly for its potential health benefits and improved nutritional profiles. Studies have explored the impacts of various seed oils, such as melon, pumpkin, hemp, and chia, as partial or complete substitutes for animal fats in different meat products, such as burgers, sausages, and salami. These substitutions improve the fatty acid composition, reduce saturated fat content, and enhance the overall healthfulness of these foods.

The use of melon and pumpkin seed oils in deer burgers was investigated by Martínez et al. (2023b). They found that these oils improved the fatty acid profile of the burgers by increasing polyunsaturated fatty acids like linoleic acid and also resulted in positive sensory evaluations from consumers. Likewise, Martínez et al. (2023a) substituted pork fat with emulsified chia seed oil in sausages, achieving a softer texture and a more desirable fatty acid profile, which included an increase in linoleic and linolenic acids. These findings align with other studies showing that seed oils can serve as valuable fat replacements while maintaining or improving the sensory qualities of meat products (Botella-Martínez et al., 2023; Hamed et al., 2024).

The nutritional benefits of replacing animal fats with seed oils extend beyond the reduction of saturated fats. Studies have demonstrated that incorporating seed oils in food products can increase levels of beneficial omega-3 and omega-6 fatty acids, which are associated with improved cardiovascular health and reduced inflammation. For instance, hemp seed oil, as explored by Papatzimos et al. (2024), was shown to replace both animal fats and sodium nitrite in fermented salami, improving the product's nutritional value, sensory characteristics, and shelf life. The substitution of chia and grape seed oils in cooked sausages was observed by Momchilova et al. (2023), who noted significant improvements in the nutritional profile, including higher unsaturated fatty acid content. These studies collectively highlight the potential of seed oils in enhancing the nutritional quality of meat products while offering a healthier alternative to traditional fat sources (Zhang & Li, 2024).

The technological aspects of using seed oils as fat replacers have also been explored, with several studies investigating the effects of these oils on the physical properties of the products. Emulsions of seed oils, such as those made from melon, pumpkin, and hemp, were found to influence the texture and stability of meat products, sometimes leading to slight changes in product hardness, cohesiveness, and moisture retention. For example, the study by Botella-Martínez et al. (2023) demonstrated that the gelled emulsion of hemp seed oil and buckwheat flour was a viable alternative to pork fat in Alheiras, a Portuguese meat product. Although the substitution affected the lipid oxidation rates, leading to increased oxidation in the reformulated samples, the health benefits of the higher unsaturated fatty acid content outweighed the drawbacks. This finding highlights the balance between achieving healthier product formulations and managing the challenges of oxidative stability (Difonzo et al., 2024; Momchilova et al., 2023).

In terms of sensory properties, the substitution of animal fats with seed oils often results in favourable evaluations, although some formulations may require adjustments to texture and flavour to align with consumer preferences. The sensory characteristics of the reformulated products, such as odour, texture, and taste, are crucial for consumer acceptance. Studies by Martínez et al. (2023b) and Avci et al. (2023) found that although the reformulated products often exhibited a softer texture or slight changes in flavour, they were still positively received by consumers. This suggests that the nutritional improvements offered by seed oils, such as lower saturated fat content and higher polyunsaturated fat content, do not negatively impact consumer preferences when appropriately formulated.

DISCUSSION AND CONCLUSION

Recent advancements in oil extraction methods, such as UAE, have shown considerable promise in enhancing both the yield and quality of seed oils. These methods have proven to be more environmentally sustainable compared to traditional techniques. Oils extracted through such processes often exhibit favourable fatty acid profiles and improved oxidative stability. Seed oils have also been studied for their role in developing healthier food formulations, such as plant-based fat substitutes. Emulsion gels made from sunflower and palm stearin seed oils, have similar textural and crystallisation properties as animal fats, suggesting their potential use in lower-fat food products. In industrial applications, seed oils derived from sources like *Madhuca indica* (mahua) seeds have potential as green alternatives to replace petroleum-derived substances in the production of polyurethane-based anticorrosive coatings. The trend of using waste by-products such as papaya seed oil has further extended to the bioactive potential of seed oils, particularly their antioxidant properties, which contribute to both human health and waste reduction. Seed oils also contribute to food preservation, with specific oils like *Lycium barbarum* improving the storage stability of products such as chocolate through oleogel formation. These innovations help to lower the amount of saturated fat that is present in food while maintaining desired product characteristics. In addition, research into refining extraction methods has led to more efficient and sustainable processes, predicting key factors like particle size and moisture content to optimise oil yields. The incorporation of seed oils into low fat mayonnaise and multilayer emulsions demonstrate the ability of seed oils to provide improved texture and enhanced oxidative stability to food products. Overall, seed oils are paving the way for sustainable, health-promoting solutions across diverse industries.

Due to their high levels of essential fatty acids, polyphenols, and antioxidants, seed oils like muskmelon, mango, guava, and grape seed oils are of very broad benefit to human beings. These oils are especially beneficial for heart health, lowering cholesterol, and reducing inflammation. Muskmelon seed oil, containing high linoleic acid, is related to cardiovascular well-being, while guava seed oil with high polyunsaturated fatty acids is a viable alternative to traditional fats in food processing as a healthy substitute. Beyond their nutritional value, the seed oils also play an important role in food preservation and processing. Mango seed oil has been used as a substitute for cocoa butter in chocolate to improve both its antioxidant content and sensory qualities because it contains high amounts of palmitic and stearic acids. Grape seed oil contributes to the stability and taste of salad dressings, while also reducing fat content. In the pharmaceutical and cosmetic industries, seed oils are incorporated into products due to their bioactive properties. By-products like protein hydrolysates from chia seed meal have considerable health benefits, including antioxidant and antidiabetic effects, thus advancing the nutraceutical field. The sustainable use of these by-products shows the potential for waste reduction while at the same time creating valuable ingredients for functional foods. Seed oils such as pomegranate and grape seed oils have been discovered to contain antioxidant activity that maintains the freshness and quality of fruits and vegetables. This also indicates their significance in improving the shelf life and nutritional value of food products. The increasing volume of studies on seed oils reflects their significance in creating healthier and more sustainable foods, while also stimulating innovation in non-food sectors.

Studies on seed oils like melon, pumpkin, hemp, and chia have shown that replacing animal fats with these oils can improve the fatty acid composition of meat products, including burgers, sausages, and salamis. This substitution reduces saturated fat levels and increases beneficial polyunsaturated fatty acids, including linoleic acid and omega-3 fatty acids, which are known for promoting cardiovascular health and reducing inflammation. Certain studies have established that emulsified seed oils in food products such as deer burgers and sausages not only enhance their fatty acid profiles but also improve sensory qualities, including texture and taste, which are crucial for consumer acceptance. The incorporation of hemp seed oil in fermented salami has improved its nutritional content, organoleptic properties, and shelf life, while also reducing the need for sodium nitrite. This substitution of animal fats by seed oils has some challenges, particularly concerning oxidative stability, because the high unsaturated fatty acid content will raise the rate of oxidation, which could affect product shelf life. However, the overall health benefits of these seed oils will generally overshadow the stability issues. Sensory properties are another area of concern, as changes in texture and flavor may occur during product reformulation. Although some formulations may require adjustments to meet consumer preferences, studies have found that, when properly formulated, the nutritional improvements do not significantly compromise consumer acceptance. Therefore, replacing animal fats with seed oils presents a promising opportunity to improve the healthiness of meat products without sacrificing, and even enhancing, their consumer acceptability. However, addressing oxidation issues and optimising texture and further optimising the texture and formulation of these products will be essential to fully realise the potential of these oils in the marketplace.

LIMITATIONS AND FUTURE DIRECTIONS

There are a few limitations to consider that may have influenced the comprehensiveness of the findings. It was challenging to draw direct comparisons or general conclusions because of the observable variety in the types of oil, extraction techniques, and health outcome measurements. A significant gap in the literature is the lack of standardised methods to evaluate the health impacts of seed oils in human populations. Many studies have relied on animal models or in vitro data, with limited human clinical trials to support health claims. Most research tends to focus on individual components, such as fatty acids or antioxidants, rather than assessing the holistic effects of seed oils. Although some short-term studies have reported encouraging results, there is still limited evidence on the long-term health effects, particularly when seed oils are consumed in large amounts or over extended periods.

Extraction and processing methods are another area of concern. Some of the most common methods include cold-pressed extraction or supercritical carbon dioxide (CO_2) extraction. However, there is little to no agreement on which method maximises the health benefits of seed oils. The refining processes are also of concern since it can impair the nutritional value and reduce the bioactive compounds of the oils. As demand for plant-based functional foods grows, it is crucial to study the best ways these oils can be processed and added into functional foods. The differences in extraction and processing methods, coupled with factors such as storage conditions and oil stability, can lead to wide variations in quality and efficacy. This calls for more coordinated research efforts to understand how each of these factors influences health outcomes.

Future research should focus on standardising extraction protocols and analytical methods used in evaluating seed oils, which would improve consistency and allow for better cross-study comparisons. Long-term human clinical trials are essential to validate the therapeutic effects of seed oils. These should ideally include diverse population groups, dietary patterns, and health markers. Further exploration into the biochemical mechanisms of action and the synergistic potential of combined bioactive compounds would provide critical insights to support the integration of seed oils into functional foods. Life cycle assessments and economic feasibility studies will be useful in assessing their potential as environmentally friendly alternatives to traditional fats, both in food and industrial applications.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Higher Education Malaysia under Fundamental Research Grant Scheme (FRGS) Vot K516 (FRGS/1/2024/WAS09/UTHM/02/1), as well as the Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (Vot Q408) and under Postgraduate Research Grant (GPPS) Vot Q611.

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