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The halal positive list: streamlining the path to certification

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Abstract

Halal certification, a crucial religious guideline for Muslims, has evolved beyond merely excluding meat and alcohol to encompass a wide range of products, including food, cosmetics, chemicals, and pharmaceuticals. This expansion necessitates thorough examinations of ingredient sourcing and processing methods, making certification more complex and time-consuming. The Halal Positive List (HPL) was introduced to streamline this process and developed by Islamic scholars, food scientists, and industry experts. The HPL aims to simplify certification by providing a comprehensive list of pre-approved ingredients, saving time and resources while ensuring consistency and trust. However, challenges remain, particularly in achieving universal acceptance among certifying bodies and addressing the potential toxicity of single-molecule compounds. To enhance compliance, we propose the Halal-Tayyib Positive List (HTPL), which verifies the halal nature and the wholesomeness (*tayyib*) of ingredients, ensuring they are safe and ethically sourced. The framework categorises ingredients as non-critical, critical, or highly critical, streamlining the halal certification process with a straightforward, standardised approach.

1. Introduction

Halal represents a crucial religious guideline for Muslims, a regulatory challenge for halal certification bodies, and a valuable marketing label for non-Muslim businesses (Dzikrulloh & Koib, 2021). For Muslim consumers, a halal certificate signifies alignment with their halal lifestyle. For non-Muslim consumers, it is an added layer of quality control (Wilkins et al., 2019). Traditionally, halal certification focused primarily on ensuring that ingredients were free from meat and alcohol. However, the scope of halal certification has expanded significantly. Today, it encompasses food, cosmetics, chemicals, pharmaceuticals, and devices (Alzeer & Abou Hadeed, 2020). This expansion has made the certification process more complex and time-consuming, requiring detailed laboratory testing, regular audits, and comprehensive certification reviews to thoroughly assess ingredient sourcing, production methods, and processing techniques.

The complexity of halal certification is closely related to the number of ingredients involved in production. Companies producing cosmetics, chemicals, and pharmaceutical products utilise various ingredients, making it essential to devise methods to facilitate halal certification (Alzeer, 2021). The Halal Positive List (HPL) was introduced to address the issues developed by Islamic scholars, food scientists, and industry experts. This list emphasises transparency and efficiency, simplifies manufacturer certification procedures, and saves time and resources.

By providing a comprehensive repository of approved ingredients, the HPL ensures consistency and builds trust within the halal industry, establishing a standardised framework for ingredient approval. This approach facilitates more straightforward and faster certification and reinforces the integrity and reliability of halal-certified products. The HPL is gradually being integrated into halal certification procedures. However, its widespread acceptance faces challenges due to differing schools of thought and the need for a universally accepted classification system among all halal certifying bodies (Zailani et al., 2017).

In this context, we aim to explore the various aspects of implementing the HPL in auditing procedures. By examining the advantages and disadvantages, challenges, and critical considerations related to the integration of the HPL, we aim to provide comprehensive insights into its potential impact on halal certification processes. Through this exploration, we seek to contribute to a deeper understanding of how the HPL can reshape auditing practices and ensure robust halal compliance.

2. Ensuring halal compliance with HPL

Ingredients are classified into non-critical, critical, and highly critical (Figure 1) to ensure comprehensive compliance with halal processing and production standards and facilitate their inclusion in the HPL. This systematic classification is essential for determining the necessary verification and certification steps and ensuring that all ingredients meet halal standards (Giyanti et al., 2020).

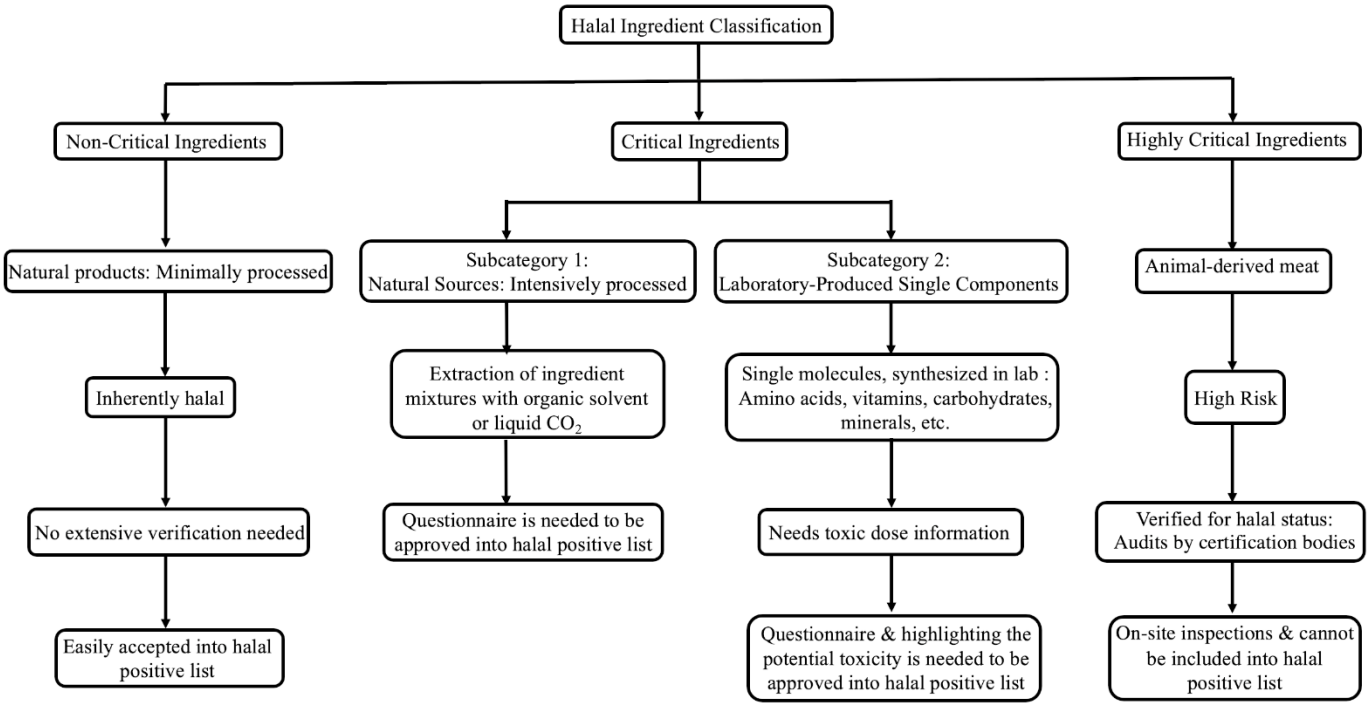

Figure 1: Halal positive list flow: classifies ingredients for halal list based on verification complexity.

2.1 Non-critical ingredients

Non-critical ingredients are naturally occurring and do not undergo processes that compromise their halal status. These inherently halal ingredients, like plant-based items such as fruits and vegetables, are generally included in the HPL without extensive inspection. Minimal processing (e.g., washing and cutting) and their low risk of contamination make them automatically acceptable, ensuring compliance with halal standards without the need for detailed verification.

2.2 Critical ingredients

Critical ingredients, whether naturally occurring or laboratory-produced, undergo processes that can impact their halal status. For instance, natural and artificial flavourings require thorough verification to ensure compliance with halal standards. Natural flavourings, often extracted using organic solvents like ethanol and a mixture of ingredients, require a detailed questionnaire for approval for the HPL (Alzeer & Abou Hadeed, 2016). This process assesses the entire production to ensure no non-halal substances are involved. Artificial flavourings, typically synthesised as single molecules, undergo multiple processing steps such as extraction, isolation, and purification, requiring even more rigorous verification. Single-molecule components have the potential to be toxic. However, dose determines toxicity. It is crucial to highlight in the questionnaire that such products have the potential to be toxic and must be used within a tolerable dose to be approved for the HPL. This comprehensive evaluation ensures that the ingredients are permissible and safe for consumption, adhering to strict halal standards.

2.3 Highly critical ingredients

Highly critical ingredients have a higher risk of being non-halal due to their origin, processing methods, or potential for cross-contamination. These ingredients often come from animal sources or involve complex processing that requires thorough verification. For example, ingredients derived from animal sources must be verified for their halal status by ensuring the animals are sourced and slaughtered according to halal guidelines. Highly critical ingredients cannot be included in the HPL; they must have a halal certification verifying their origin and the slaughtering process. The halal certification process is strict and includes a comprehensive questionnaire and on-site inspections and audits carried out by the certification bodies. During these audits, both the documentation and the physical processes are thoroughly checked. For example, auditors review sourcing documentation to ensure that all raw materials are sourced from halal-certified suppliers and inspect production lines to ensure no cross-contamination between halal and non-halal products. They also assess cleaning protocols, equipment and storage practices to ensure full compliance with halal standards. This practical verification is essential to ensure that all ingredients are permitted and safe for consumption by halal principles (Annabi & Ibidapo-Obe, 2017).

The categorisation and verification processes ensure that all ingredients (non-critical and critical) included in the HPL adhere to stringent halal standards. This rigorous approach involves a thorough assessment of both the inherent nature of the ingredients and the processes they undergo. By categorising ingredients into non-critical, critical, and highly critical, the framework systematically evaluates each ingredient based on its potential risks and the complexity of its production process.

3. Halal-Tayyib positive list

According to *Shari'ah* law (*Hokm Shari'ah*), the default status of things is considered halal unless evidence is presented proving otherwise. Additionally, actions must comply with *Shari'ah* principles. To determine whether something is halal, both the nature of the item and the actions or processes it undergoes must be examined. This dual perspective explains

why the *Qur'an* frequently mentions 'halal' and '*tayyib*' when discussing food. In this context, 'halal' refers to the intrinsic nature of an item, while '*tayyib*' pertains to the processes involved in its preparation and handling (Alzeer *et al.,* 2018).

For example, while fish is inherently halal, the conditions under which it is raised determine whether it meets the *tayyib* standard. Fish raised in contaminated waters would not be considered *tayyib*, even though it is naturally halal. Conversely, if an inherently non-halal item, such as pork, is produced in a *tayyib* (wholesome) environment, it remains non-halal due to its intrinsic nature. Therefore, when determining the halal status of any ingredient, it is essential to consider its inherent nature and process. *tayyib* ensures that, upon consumption, the individual feels comfortable, which is best achieved when the production process aligns with halal lifestyle principles. This results in healthy food produced in a clean and hygienic environment.

To verify the HPL, it is essential to evaluate each ingredient from two perspectives: its halal nature and the *tayyib* nature of the process. Ingredients composed of single molecular components, which have a significant potential to influence health status, require special consideration. These ingredients, often used as flavourings, stabilisers, emulsifiers, or nutritional enhancers, must be rigorously assessed for their safety and compliance with halal and *tayyib* standards.

For instance, vitamins, minerals, hormones, ions, and metal chelators are beneficial only when used within their effective doses (Alzeer *et al.,* 2021). Overdosing on these substances can lead to toxicity (Zimmermann *et al*., 2019). Therefore, when approving such ingredients for the HPL, it is necessary to include their toxic doses or indicate their potential toxicity if used beyond the tolerable dose. This ensures compliance with the *tayyib* principle, where safety is paramount (Bast & Semen, 2024).

For example, acetic acid can be produced by aerobic fermentation of fruits, such as apples, to generate apple vinegar, which contains approximately 5% acetic acid (Alzeer & Abou Hadeed, 2016). In this case, the acetic acid is inherently halal. Because it is produced from natural ingredients through a *tayyib* process, the product is Halal-Tayyib and can be added to the HPL. Conversely, acetic acid can also be produced chemically by oxidising ethanol to create pure acetic acid as a single molecular component. Although the acetic acid ingredient is halal and the process is *tayyib*, this could lead to misunderstandings, such as the incorrect assumption that pure acetic acid can be consumed directly because it is deemed Halal-Tayyib. Apple cider vinegar is obtained through the natural fermentation of apples, preserving beneficial nutrients, enzymes and probiotics that promote digestive health and overall well-being. Pure acetic acid, on the other hand, which is often chemically produced, does not have these additional health benefits and is mainly used in industry or food processing. Although both substances have the same acid, the natural fermentation process in apple cider vinegar provides additional health benefits that chemically produced acetic acid does not.
To avoid such misconceptions, it is important to highlight that products produced and used as single molecules can be toxic if used beyond the tolerable dose (Pognan *et al.,* 2023). Therefore, critical ingredients produced from natural products must be approved through a questionnaire. For single molecular ingredients, approval should include a questionnaire and a note on the tolerable dose to ensure their safe use. Therefore, to comprehensively address all aspects of halal production, the list should be referred to as the "Halal-Tayyib Positive List". This designation ensures that the ingredients' inherent nature and processes are thoroughly evaluated, upholding the highest halal compliance and wholesomeness standards.

4. Result & discussion

The halal certification process has evolved significantly due to the growing demand for halal products. Initially, focusing on ingredients derived from animals or mixed with alcohol was sufficient (Talib et al., 2016). However, as food production became more complex, it became evident that many additives, even in small quantities, require detailed inspection. To address these challenges, halal certification bodies have increasingly relied on qualified professionals from various fields, such as food science, chemistry, and pharmacy, to evaluate ingredients and processes thoroughly. This shift has ensured a more comprehensive and accurate assessment of product compliance. The concept of HPL has been introduced to streamline the certification process (Rashid & Bojei, 2019). The HPL aims to classify ingredients as inherently halal, eliminating the need for extensive traceability and investigation. However, the HPL raises questions regarding its applicability to chemically synthesised single-molecule compounds, which may pose toxicity risks. Since toxicity is dose-dependent, new classifications are needed to ensure the safe and effective determination of ingredient status.

Given the current HPL's limitations in addressing the complexities of modern food production, we propose replacing it with a Halal-Tayyib Positive List (HTPL). This new list would confirm the halal nature of ingredients and ensure that the processes involved meet *tayyib* (wholesome and pure) standards. This dual verification ensures that ingredients are safe, ethically sourced, and processed in a manner that aligns with the holistic principles of Halal-Tayyib.

We propose classifying ingredients into non-critical, critical, and highly critical to enhance the certification process and ensure comprehensive compliance with halal and tayyib principles. This classification will facilitate the inclusion of ingredients in the HTPL, ensuring they meet both permissibility and wholesomeness standards (Table 1).

4.1 Non-critical ingredients

Inherently halal ingredients, such as essential plant-based items like fruits and vegetables, require minimal scrutiny and can be easily included in the HTPL without extensive verification.

4.2 Critical ingredients

The HTPL finds it most challenging to approve such ingredients. Therefore, it is important to classify these critical ingredients further into subcategories.

4.2.1 Subcategory 1: processed from natural sources

Ingredients in this subcategory are mixtures or compounds derived from natural sources. Examples include plant extracts or naturally derived chemicals. To ensure these ingredients comply with *tayyib* principles, a detailed questionnaire assessing the production process is required. This verification process confirms that no non-halal substances are involved during processing, ensuring the integrity of the HTP.

Table 1: Most ımportant Halal-Tayyib Positive List categories with detailed natural ingredient examples:

Category	Examples		Description
Natural Ingredients: These ingredients are derived from natural sources and are generally considered halal (Mohd Noor *et al.*, 2023)	Fruits:	Apples, bananas, oranges, grapes, berries, melons, dates, figs	These ingredients are derived directly from plants or animals and minimally processed. These ingredients can be classified as non-critical and quickly added to the Halal-Tayyib Positive List.
	Vegetables:	Potatoes, tomatoes, onions, carrots, lettuce, spinach, broccoli, mushrooms	
	Grains:	Wheat (for flour, bread, pasta), rice, barley, oats, corn	
	Herbs and Spices:	Basil, oregano, mint, parsley, thyme, cumin, cinnamon, cloves, turmeric, ginger, garlic, chilli peppers	
	Oils:	Olive oil, coconut oil, sunflower oil, canola oil, peanut oil (depending on regional interpretations)	
	Nuts and Seeds:	Almonds, walnuts, cashews, pistachios, peanuts (depending on regional interpretations), flaxseeds, chia seeds	
	Sweeteners:	Honey, maple syrup (depending on production methods)	
	Fats and Dairy	Milk, yoghurt, cheese, butter, ghee (If the flavours, additives and enzymes used in the preparation are natural and are not derived from animals)	
Food Additives: These additives enhance the taste, texture, or shelf life of food. They are pre-approved on the HPL based on their source, production process, and potential contaminants (Nazaruddin *et al.*, 2023).	Acidity Regulators:	Citric acid (E330), malic acid (E296), tartaric acid (E334): Control acidity for taste, preservation, and functionality. Phosphates (e.g., disodium phosphate, E339): Maintain a desired pH level for various functionalities like texture and microbial control.	Food additives are Substances added to food in small quantities during processing to perform various functions and are classified as critical ingredients. These substances are mainly used as single-component compounds, so they fall under subcategory 2. To be approved and added to the Halal-Tayyib Positive List, a questionnaire highlighting the potential toxicity of these ingredients is required. Some regional interpretations might exclude certain food additives derived from non-halal sources (e.g., animal-derived glycerol used in some emulsifiers).
	Emulsifiers:	Lecithin (E322), mono- and diglycerides (E471), polysorbates (E433): Help disperse and stabilise ingredients that would not usually mix (e.g., oil and water).	
	Sweeteners:	Sucrose (table sugar), fructose, high-fructose corn syrup (HFCS: limitations may apply), stevia glycosides (E960): Enhance sweetness without adding significant calories (in some cases).	
	Thickeners:	Agar-agar (E406), xanthan gum (E415), carrageenan (E407): Increase viscosity and improve texture in various food products.	
	Antioxidants:	Ascorbic acid (vitamin C, E300), tocopherols (vitamin E), BHA (E320), BHT (E321): Prevent spoilage caused by oxidation (rancidity).	
	Colourings:	Natural colours (e.g., paprika extract, turmeric), caramel (E150), and specific artificial colours (restrictions may apply based on regional interpretations): Enhance the visual appeal of food products.	
	Flavorings:	Natural flavours are derived from plants, spices, or animal sources (restrictions may apply), and some artificial flavours (restrictions may apply) enhance or modify the taste profile.	
	Leavening Agents:	Baking powder and baking soda (sodium bicarbonate, E500) raise dough by releasing carbon dioxide.	
	Sequestrants:	EDTA (E386): Bind metal ions affecting colour, flavour, or stability.	

Processing Aids: These substances are used during food processing but are not typically present in the final product. The HPL ensures they are derived from halal sources and do not introduce forbidden substances (Maqsood-ul-Haque & Veny, 2023).	Enzymes:	Amylase (breaks down starch into sugars): Used in bread making, brewing, and syrups production. Protease (breaks down proteins): Used in meat tenderisation and cheesemaking clarification. Lipase (breaks down fats): Used in cheesemaking, dairy product flavour development, and oil modification.	Those ingredients are classified as critical and belong to subcategory 1. A questionnaire describing the production process is required to be approved and added to the Halal-Tayyib Positive List.
	Filtering Agents:	Diatomaceous earth (DE) Removes solids from liquids through filtration. Perlite is a volcanic glass used for filtration and is often used in clarifying beverages. Bentonite clay: Used for clarification and stabilisation of beverages like fruit juices by absorbing unwanted proteins and haze-forming particles.	
	Fermentation Cultures:	Yeast (Saccharomyces cerevisiae): Converts sugars into alcohol and carbon dioxide in bread-making and yoghurt fermentation. Lactic acid bacteria: Convert sugars into lactic acid, used in yoghurt and cheese production and for preserving vegetables (sauerkraut, kimchi).	
	Bleaching Clays:	Activated alumina: Removes unwanted colours and impurities from oils and fats. Activated carbon (wood): A highly adsorbent material used to decolourise, purify, and remove off-flavours and odours from various food products.	
	Antifoaming Agents:	Silicone-based defoamers: Reduce and prevent foam formation during processing, often used in beverages and syrups. Vegetable oils: Certain vegetable oils can act as natural defoamers during food processing.	
Packaging Materials: These materials come into contact with food but are not consumed. The HPL focuses on ensuring they are non-reactive and do not compromise the halal integrity of the food (Bujang & Bakar, 2023).	Metals:	Tinplate steel: Often used for cans, the HPL ensures the tin coating complies with halal principles. Aluminium foil: Used for wrapping and sealing food products; the HPL considers potential contaminants introduced during processing. Stearate is an ingredient that must originate from a halal source to be considered suitable.	Packaging materials interface with food but are not meant for consumption. Critical ingredients are classified as critical ingredients and belong to subcategory 1. A questionnaire describing the production process is required to be approved and added to the Halal-Tayyib Positive List.
	Glass:	Bottles and jars: Glass is a widely used, inert material for storing food; the HPL focuses on ensuring that the glass composition does not contain any non-halal substances.	
	Plastics:	Polyethylene terephthalate (PET): Commonly used for bottles and food trays, the HPL considers the source material and potential for leaching harmful chemicals. High-density polyethene (HDPE): This material is used for rigid containers and bottles. The HPL ensures compliance with halal principles for its production process. Polypropylene (PP): Often used for films and containers, the HPL focuses on the absence of forbidden substances in the source material and additives. Stearate is an ingredient that must originate from a halal source to be considered suitable.	

	Paper and Paperboard:	Cardboard boxes are used for secondary packaging; the HPL considers potential contaminants introduced during production (e.g., glues and inks). Parchment paper is greaseproof paper used for wrapping food; the HPL ensures that the source material and coatings are halal-compliant.
	Biodegradable Materials:	Cellulose films: Derived from plant materials and used for food wrapping, the HPL considers the source and any processing aids used to ensure halal compliance. Polylactic acid (PLA) is a bioplastic derived from corn starch used for containers and cutlery; the HPL focuses on the production process and the potential for non-halal contaminants.

Note: This table provides a general overview. The specific ingredients and materials in the HTPL may vary depending on the country or certification body. It is crucial to refer to the specific HTPL used for certification and adhere to Halal-Tayyib principles.

4.2.2 Subcategory 2: laboratory-produced single components

This subcategory includes single-molecule ingredients synthesised in the lab, such as amino acids, vitamins, carbohydrates, fatty acids, minerals, ions, salts, additives, emulsifiers, stabilisers, and flavours. Inclusion in the HTPL requires a thorough approval process, starting with a comprehensive questionnaire that evaluates the ingredient's sourcing and processing methods to ensure compliance with halal standards (Sari et al., 2021). Additionally, it is recommended to provide a questionnaire with detailed information on the toxic dose or highlight the safety margin. This step ensures that these ingredients are used within tolerable doses, safeguarding consumer health and maintaining the integrity of the Halal-Tayyib principles. By incorporating this detailed verification, the HTPL confirms the permissibility of ingredients and their safety and wholesomeness for consumption.

4.3 Highly critical ingredients

Highly critical ingredients come from animals or involve complex processing, which puts them at high risk of being non-halal. These ingredients require strict certification to verify their sources and processes, ensuring animals are sourced and slaughtered according to halal guidelines (Masudin, 2023). This process includes detailed questionnaires, on-site inspections, and audits by halal certification bodies. Therefore, adding highly critical ingredients to the HTPL is not allowed.

This proposed classification and verification framework ensures a comprehensive evaluation of the ingredients and their production processes, maintaining high safety and quality standards. The shift to an HTPL reflects a thorough and integrated methodology that is better suited to the complexities of modern food production and consumer safety requirements. This approach aligns with the principles of halal and tayyib, assuring that products are both permissible and wholesome (Rahman et al., 2017).

To effectively implement the HTPL, it is essential to establish a multidisciplinary expert panel comprising Islamic scholars, food scientists, chemists, pharmacists, and industry experts. This panel will oversee the development and maintenance of the HTPL, ensuring it reflects the latest scientific discoveries and industry practices.

The HTPL will be integrated into halal certification processes by developing standardised auditing protocols covering every production stage, from sourcing to final packaging. Halal auditors will be trained to use the HTPL effectively, ensuring a streamlined certification process that saves time and resources while maintaining consistency and trust within the halal food industry. A digital platform will facilitate easy access to the HTPL, promote transparency, and enable continuous updates (Shari, 2022). Communication among scholars, scientists, manufacturers, and consumers will be encouraged to improve the HTPL and auditing practices continually. Recognising its limitations, comprehensive audits will also address other critical aspects of halal compliance, such as hygiene practices and avoiding cross-contamination (Talib et al., 2015). Establishing the HTPL as an integral component within a comprehensive halal certification framework ensures that products meet stringent halal and tayyib standards, benefiting manufacturers, consumers, and the broader halal industry.

5. Conclusions

The increasing complexity of food production poses challenges to traditional halal certification methods. Although the Halal Positive List (HPL) facilitates the certification process by providing a pre-approved list of ingredients, it is inadequate when addressing safety concerns, especially for single-molecule ingredients. This study argues for developing a Halal-Tayyib Positive List (HTPL) that considers halal acceptability and tayyib wholesomeness and provides a more comprehensive framework for certification. The multi-tiered classification system, utilising questionnaires, ensures comprehensive verification of critical ingredients. This approach ensures ingredient safety, ethical sourcing, and consumer trust, requiring a multidisciplinary expert panel and standardised auditing protocols for successful implementation. Future research could explore the economic impact of HTPL on the halal food industry and analyse the effectiveness of HTPL in different regions with varying halal certification practices. Implementing the HTPL can significantly improve halal certification processes, ensuring robust compliance with halal and tayyib principles for the benefit of manufacturers, consumers, and the halal industry.

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HALALSPHERE
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Vegan alternatives as the source of halal cosmetic products: a comparative analysis in efficiency, cost, and ethical ımplications

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Abstract

The growing demand for vegan cosmetics, projected to reach US $20 billion by 2028, presents a significant opportunity for the cosmetics industry. However, aligning vegan products with halal certification remains a challenge, especially given the prevalence of animal-derived ingredients in traditional formulations. This study explores the comparative efficacy, cost implications, and ethical considerations of vegan versus animal-based ingredients in cosmetics. Through a comprehensive analysis of existing literature and market trends, we examine the benefits of vegan cosmetics, such as their cruelty-free production and reduced environmental impact, alongside the barriers to halal certification. The research identifies key vegan alternatives—such as agar, carrageenan, soy, and plant-based colourants—that offer similar functional benefits to animal-derived ingredients like collagen, gelatin, and keratin but often require additional processing or formulation adjustments to achieve comparable results. Despite these challenges, vegan alternatives offer cost-effective solutions and align more easily with ethical standards, including halal compliance. The study concludes that heightened consumer awareness, alongside innovative product formulations, can facilitate the acceptance of vegan and halal-certified cosmetics for ethical consumption practices in the industry.

1. Introduction

The cosmetics industry has seen a significant rise in demand for halal products, driven by increasing consumer awareness of the ingredients used in personal care products and a growing desire for products that align with ethical and religious principles (Elgharbawey, 2019). Halal cosmetics comply with Islamic *Shari'ah* law and are marketed as solutions to these consumer concerns by ensuring that ingredients and manufacturing processes avoid prohibited substances. However, halal cosmetics face particular challenges that distinguish them from vegan products, especially regarding ingredient sourcing and certification. While halal guidelines prohibit certain animal-derived ingredients—such as those from pigs, blood, and predatory animals—other animal-based ingredients like gelatin, carmine, and lanolin remain permissible under halal standards. This creates confusion among consumers who may perceive these products as non-compliant with ethical principles, even though they meet halal criteria. Consequently, the market for halal cosmetics lacks clarity and transparency, leading to potential consumer mistrust and highlighting the need for more precise guidelines and certification processes (Coherent Market Insights, 2023; Ahmed, 2024).

In contrast, vegan cosmetics offer a more definitive ethical stance by excluding all animal-derived ingredients, positioning them as a response to the growing consumer demand for cruelty-free and environmentally sustainable products. However, for halal cosmetics, the challenge extends beyond avoiding animal-derived ingredients prohibited by *Shari'ah* law (Ngah *et al.*, 2021; Hussaini *et al.*, 2024). It also involves adapting to the rising demand for plant-based, cruelty-free ingredients without compromising the product's performance or stability. Including vegan ingredients such as agar, carrageenan, soy-based alternatives, and plant-derived colourants could address halal and ethical consumer preferences. Nonetheless, integrating these ingredients into halal-certified cosmetics presents challenges, including additional processing to match the performance of traditional animal-derived ingredients.

2. Literature review

2.1 Halal cosmetic: an emerging market

Halal cosmetics are products that conform to Islamic principles and values, ensuring the purity and wholesomeness of their ingredients while simultaneously avoiding substances considered impure or *haram* (forbidden) in Islam (Elgharbawy, 2022; Hussaini *et al.*, 2024). It includes a range of personal care and beauty products such as skincare, haircare, and makeup items, and they have become integral in the daily routines of Muslims worldwide. Halal cosmetics have evolved from a niche market into a growing industry driven by religious and ethical considerations (IMARC, 2024; Hussaini *et al.*,2024). While Muslim consumers predominantly influence the halal cosmetics market, an increasing number of non-Muslim consumers are also attracted to these products due to

their perceived purity, transparency, and ethical production standards (Ibrahim, 2023; Isa *et al.*, 2023; Research & Market, 2024).

2.1.1 Consumer preferences across regions

The demand for halal cosmetics is driven by regional variations in consumer preferences, with distinct patterns emerging worldwide. Southeast Asia is one of the primary regions that are leading the charge due to the high percentage of Muslim populations. Countries like Indonesia, Malaysia, and Singapore are at the forefront of halal cosmetic consumption. Indonesia is the largest Muslim-majority country globally, seeing a sharp rise in demand for halal-certified beauty products (Ibrahim, 2023; Fortune Business Insights, 2025). This is partly due to religious observance and a growing trend toward cleaner, more ethically sourced products.

Indonesia is expected to remain a leader in halal cosmetics consumption. On the other hand, Malaysia has emerged as a regional hub for halal-certified products, owing to its robust halal certification process, which is one of the most respected worldwide. Malaysian brands, such as Wardah Cosmetics and Inai Beauty, are prominent in local and international markets, setting trends in halal beauty formulations. Furthermore, Saudi Arabia and the United Arab Emirates (UAE) are key markets in the Middle East, where halal cosmetics are increasingly popular due to the intersection of wealth, religious practices, and heightened awareness of ethical beauty (Sugibayashi *et al.*, 2019; Ibrahim, 2023; Salaam Getaway, 2024).

In non-Muslim-majority countries, particularly in Europe and North America, halal cosmetics are gaining popularity not only among Muslim consumers but also among those who prioritise ethical consumption. Non-Muslim consumers in the United States, United Kingdom, and France are increasingly attracted to halal products because of their cruelty-free status, clean ingredient profiles, and ethical production methods. This trend leads to the rising popularity of clean beauty and vegan products, emphasising safety, sustainability, and transparency (Isa *et al.*, 2023; Salaam Getaway, 2024).

2.1.2 Leading countries and market trends in halal cosmetics

Among the countries at the forefront of halal cosmetics, Malaysia, Indonesia, and the UAE stand out due to their market size, religious influence, and regulatory frameworks that make it easier for halal-certified products to gain market acceptance (IMARC, 2024; Fortune Business Insights, 2025). According to Markets and Data (2023), Malaysia's halal certification process is one of the most comprehensive in the world, establishing the country as a global leader in halal cosmetic manufacturing and export. With its burgeoning middle class and a growing demand for halal-certified products, Indonesia is also poised to become a dominant player in the market (Inkwood Research, 2023). With their high disposable incomes and Muslim populations, Saudi Arabia and the UAE present an attractive market for luxury and mass-market halal cosmetics (Salaam Getaway, 2024). On a global scale, Europe and North America are expected to become more important markets for halal cosmetics in the coming years. Increasing consumer awareness about animal welfare, transparency, and product ingredients drives interest in halal certified beauty products beyond traditional Muslim communities (Research & Market, 2024).

2.1.3 Future growth projections of halal cosmetics

The global halal cosmetics market is expected to grow at a compounded annual growth rate (CAGR) of 12.1% from 2022 to 2030 (Markets and Data, 2023). This growth is fueled by an expanding Muslim population, rising consumer awareness regarding ethical and clean beauty products, and an increasing focus on cruelty-free and sustainable manufacturing processes. Key market players are poised to capture a share of this growth. Major multinational corporations such as L'Oréal, Unilever, and Estée Lauder increasingly seek halal certification for their products, recognising the market's potential (Research & Market, 2024). These companies are introducing halal-certified products and focusing on aligning their existing product lines with halal standards to cater to a broader consumer base.

In addition, local stakeholders such as Wardah Cosmetics (Indonesia) and Inai Beauty (Malaysia) continue to innovate by offering products that meet both halal standards and the growing consumer demand for ethical and natural beauty solutions. E-commerce platforms also play a pivotal role in the global distribution of halal cosmetics, particularly in regions where physical retail access may be limited (Research & Market, 2024; Salaam Getaway, 2024). Digitalising halal beauty products allows brands to reach international consumers, including non-Muslim-majority countries, thus expanding the market reach (Santos *et al.*, 2023).

2.2 Vegan alternatives as a source of halal cosmetics products

Vegan cosmetics are products formulated without any animal-derived ingredients or by-products, including standard components like beeswax, lanolin, and certain colourants. These products are typically also cruelty-free, meaning they are not tested on animals (Lee, 2022). The global cosmetics market, valued at approximately $429.2 billion in 2022, is projected to reach around $864.6 billion by 2032, growing at a compound annual growth rate (CAGR) of 7.1% from 2023 to 2032. Within this broader market, the demand for vegan and cruelty-free cosmetics is rising significantly, driven by increasing consumer awareness regarding ethical and sustainable practices in product formulation (Fortune Business Insights, 2025).

The use of vegan alternatives as the source of halal cosmetic products has been gaining attention in recent years as they do not contain animal-based ingredients that may not be halal and may irritate the skin (Rawat, 2022). However, there are more factors to consider while examining vegan cosmetics and their potential halal accreditation. According to Yacoubou (2020), the assessment of animal ingredients is one of the factors to consider when looking at vegan cosmetics and their potential halal status. There may be cosmetics that are not vegan but would be halal based on the assessment of animal ingredients.

Moreover, testing cosmetics on animals is unnecessary and wasteful when businesses can make inventive solutions using hundreds of components with a history of safe usage that does not require more testing. For instance, natural ingredients are used in cosmetics. Consumers know the advantages of using

chemical-free, environmentally friendly vegan cosmetics (Rawat, 2022). As a result, it encourages the creation and use of alternatives that do not involve using animals for the benefit of both humans and animals as well as the environment.

2.2.1 The rise of vegan cosmetics: demand, health awareness, and demographic shifts

Several factors motivate consumers to opt for vegan cosmetics. Ethical concerns are at the forefront, and many individuals are increasingly aware of animal welfare issues and prefer products that do not involve animal exploitation (Huyen & Viet, 2024). Additionally, health consciousness plays a significant role in consumer choices. Many people are concerned about the potentially harmful effects of synthetic chemicals and animal-derived ingredients in cosmetics, leading them to favour natural and organic formulations that align with vegan principles (Lee, 2022; Huyen & Viet, 2024). Environmental awareness also drives this trend as consumers scrutinise the environmental impact of the cosmetics industry. Vegan products often come with eco-friendly packaging and sustainable sourcing practices, appealing to environmentally conscious shoppers. Moreover, the influence of social media cannot be underestimated; platforms like Instagram and TikTok have amplified the visibility of vegan beauty brands, shaping consumer preferences through trends and endorsements from influencers (Nguy *et al.*, 2023; Santos *et al.*, 2023).

Another notable factor for the rise of vegan cosmetics is the increasing health and wellness awareness among consumers (Huyen & Viet, 2024). Vegan cosmetics often promise to be free from harmful chemicals, making them more appealing to consumers seeking natural and non-toxic beauty products. For instance, the health benefits of using vegan cosmetics—such as their potential to lower the risk of skin conditions like acne or hyperpigmentation—are now widely recognised. Some animal-based products, such as lanolin or collagen, may cause skin irritation or allergic reactions. Consequently, many consumers opt for vegan alternatives that utilise plant-based oils, extracts, and other botanicals perceived as gentler on the skin (Wright, 2018; Srivastava, 2024).

Demographic shifts are also influencing the rise of vegan cosmetics. Younger generations, particularly Millennials and Gen Z, are at the forefront of this movement. These groups are concerned with the ethics of product ingredients and are highly aware of their personal health and environmental sustainability (Shim *et al.*, 2024). As consumers born into a world with heightened environmental and ethical awareness, these generations prioritise cruelty-free, vegan, and eco-friendly products in their beauty routines. Studies indicate that Millennials are leading the shift toward vegan lifestyles in their cosmetic choices; they are motivated by sustainability and animal rights and are willing to spend more on products that reflect these beliefs (Hammet, 2019; Shim *et al.*, 2024). Gen Z is particularly notable for favouring vegan products for ethical reasons and their growing awareness of social justice aspects of production and consumption (Shim *et al.*, 2024).

Moreover, the increased access to vegan alternatives has further fueled demand. The growing availability of affordable, high-quality vegan cosmetic products has made them more accessible to a broader consumer base. (Coherent Market Analysis, 2024). Brands like PHB Ethical Beauty and Draphee have emerged as key players in this market, offering a range of organic and vegan products that cater to health-conscious consumers. These brands are increasingly available through major retail outlets, online platforms, and drugstores, making it easier for consumers to purchase them without the premium price tag often associated with organic and cruelty-free cosmetics. As vegan cosmetics become more mainstream, their popularity extends beyond traditional vegan consumers to the general population seeking safer and more ethical alternatives in their beauty routines (Santos *et al.*, 2023).

2.2.2 Potential benefits of vegan ingredients in cosmetic formulations

Incorporating vegan ingredients in cosmetic formulations offers several significant advantages that appeal to consumers and manufacturers. One of the primary benefits is the reduction of allergens. Vegan products often contain fewer allergens than traditional cosmetics, which may include animal-derived components, making them suitable for sensitive skin types. Many consumers with allergies or sensitivities find that plant-based ingredients are gentler and less irritating than synthetic or animal-derived substances, which can lead to adverse reactions (Lee, 2022; Formula Botanica, 2023). This gentleness on the skin is crucial for individuals seeking effective yet non-irritating cosmetic options.

Another important benefit is sustainability. Vegan ingredients typically require less resource-intensive farming practices compared to animal farming, which is known for its high environmental impact. The production of plant-based ingredients generally leads to lower carbon footprints and promotes biodiversity (Visser, 2023; Sasounian *et al.*, 2024). By choosing vegan cosmetics, consumers make a personal choice and contribute to broader environmental welfare, as these products often avoid the ecological degradation associated with animal agriculture.

2.2.3 Challenges in sourcing vegan ingredients for halal cosmetics

Vegan alternatives, while offering clear advantages for halal cosmetics, sourcing these ingredients presents several technical challenges, particularly regarding processing methods and certification requirements. One critical challenge is the use of alcohol in extraction processes. While vegan cosmetics avoid animal-derived components, the use of alcohol (often ethanol) in extracting plant-based ingredients can pose compliance issues with halal standards. Islamic law prohibits intoxicants, including ethanol, regardless of their plant origin. Even trace amounts of alcohol residues in the final product may not be acceptable for strict halal certification. (Cerioli, 2023). To address this, manufacturers must explore non-alcoholic extraction methods like cold-pressing or steam distillation to ensure compliance.

Another significant issue is cross-contamination during production. Many cosmetic manufacturing facilities handle vegan and animal-derived ingredients, risking contamination from *haram* substances such as gelatin or beeswax. This necessitates strict cleaning protocols and separation between production lines to maintain halal and vegan integrity (Sugibayashi *et al.*, 2019; Hussaini *et al.*, 2024). Additionally, some vegan ingredients may be processed using animal byproducts. For instance, glycerin can be derived from both plant and animal sources. If sourced from animals, it would be considered *haram* under halal principles. Manufacturers must ensure comprehensive traceability to prevent the indirect use

Table 1. Comparative analysis of traditional ingredients and vegan alternatives in cosmetic products.

Traditional Ingredients (May be derived from pig)	Vegan Alternatives	Efficacy Comparison	Cost Implications	Ethical Remarks
Animal-based collagen is Derived from animal collagen, skin, and bones (e.g., pig, fish, cows) and used for stabilising face creams, lotions, and shampoos (Cristiano & Guagni, 2022; Hussaini *et al.*, 2024).	**Agar, Carrageenan, Gelatin**	Agar and Carrageenan provide similar thickening effects but may not offer the same long-lasting moisturising effects as animal collagen. Gelatin is a good alternative for texture but may not provide the same stability (Hoang *et al.*, 2021; Lestari *et al.*, 2019).	It can be less expensive but may need additional processing for stability and texture (Hoang *et al.*, 2021; Lestari *et al.*, 2019).	Animal-derived ingredients raise ethical concerns about animal welfare. Vegan alternatives are more easily halal-certified and cruelty-free, aligning with ethical and sustainability values.
Animal-based gelatin is Derived from animal bone, skin, tendon, and cartilage and is used for moisturising (Hussaini *et al.*, 2022).	**Soy products, Black beans, Seeds**	Soy and beans provide moisturising benefits but may not match animal collagen's skin elasticity and anti-ageing properties (Kim *et al.*, 2021).	It may be cheaper, but formulations could require additional ingredients to boost effectiveness, thus increasing total product cost (Kim *et al.*, 2021).	Animal gelatin involves exploitation concerns; plant-based alternatives are more ethical and easily halal-compliant.
Animal-Based Keratin (Hair Care) Derived from human or animal sources (goose, duck, swine bristles). Used as a conditioning agent, fragrance, and anti-agent (Cristiano & Guagni, 2022).	**Seeds, Legumes, Oatmeal**	Plant proteins may offer conditioning but are less effective than animal keratin for repairing deep hair damage (Qin *et al.*, 2022).	It is often less expensive but may require more complex formulations to achieve the same results (Qin *et al.*, 2022).	Animal keratin raises ethical issues regarding animal sourcing, while plant proteins are cruelty-free and more sustainable.
Carmine (Colorant) Made from crushed beetles, it is used in red colouring for products (e.g., lipstick) (Cristiano & Guagni, 2022).	**Beetroot powder, Hibiscus extracts, Mica Powder**	Vegan colourants like beetroot powder and hibiscus offer good colour payoff but may not provide the same vibrancy or long-lasting intensity as carmine (Abrar *et al.*, 2024).	Plant-based colourants are usually more affordable than carmine but may require complex formulation adjustments to match the colour intensity and longevity (Abrar *et al.*, 2024).	Carmine's insect origin may not meet halal standards (Mahyeddin, 2020), whereas plant-based colourants offer cruelty-free, halal-friendly alternatives.

of animal derivatives during processing (Hussaini *et al.*, 2024; Halal Food Council USA, 2024).

Manufacturers require transparency in their supply chains to guarantee that vegan ingredients are also halal-compliant. Some ingredients may seem vegan but could involve non-halal substances or methods during manufacturing (Cerioli, 2023). As consumer demand for both certifications rises, collaboration with suppliers is crucial to ensure ethical sourcing practices (Sugibayashi *et al.*, 2019; Halal Food Council USA, 2024). Finally, obtaining dual certifications for both halal and vegan products adds complexity. The certification processes involve detailed evaluations of sourcing, processing methods, and adherence to ethical standards (Halal Food Council USA, 2024). Hence, addressing these technical challenges is essential for successful halal vegan cosmetics development in this growing market.

3. Materials and methods

This study compares traditional animal-derived ingredients such as (1) collagen, (2) gelatin, (3) keratin, and (4) carmine with their vegan alternatives like agar, carrageenan, soy, seeds,beetroot powder, and hibiscus extracts in cosmetic formulations. The analysis focuses on three key factors: efficacy, cost, and ethical considerations. Efficacy was assessed by comparing the functional performance of the ingredients, including their effects on moisturising, texture, and stability. Cost implications were evaluated by considering the price of ingredients and the potential need for additional formulation adjustments. Ethical considerations were also discussed, particularly regarding halal certification and cruelty-free standards. The findings highlight the trade-offs between traditional and vegan ingredients, with vegan alternatives offering ethical and regulatory benefits while sometimes requiring more complex formulations for similar performance. The articles and studies selected for the review were analysed and synthesised to provide an overview of the potential benefits of using vegan alternatives as the source of halal cosmetic products.

4. Results and discussion

Table 1 examines traditional cosmetic ingredients, many of which are derived from animal sources (including pigs), and their vegan alternatives. The focus is on understanding the benefits of incorporating natural, plant-based ingredients in cosmetic formulations. The findings are presented in a systematic and explicit tabular format.

4.1 Efficacy of animal-derived ingredients VS. vegan alternatives

The results suggest that animal-based ingredients, such as collagen, gelatin, keratin, and carmine, effectively achieve desirable cosmetic outcomes due to their unique molecular structures resembling those found in human skin or hair. Animal-derived collagen, in particular, is known for its superior ability to stabilise and moisturise cosmetic products, essential in anti-ageing formulations (Hussaini *et al.*, 2024). It is also crucial for promoting skin elasticity and moisture retention, which are difficult to replicate with vegan alternatives (Cristiano & Guagni, 2022). However, animal-derived collagen and gelatin use raises concerns among consumers who adhere to halal principles, as these products must be sourced from halal-certified animals and processed according to halal guidelines to be considered permissible (Hussaini *et al.*, 2024). The inability to guarantee the halal status of animal-derived collagen in many products limits its appeal to Muslim consumers, who are increasingly seeking vegan or plant-based alternatives that are more easily certified as halal.

In contrast, plant-based ingredients such as agar, carrageenan, and gelatin alternatives are inherently suitable for halal products as they do not involve animal-derived sources. While these vegan alternatives provide similar thickening effects, they may not offer the same long-lasting moisturising benefits or skin elasticity as animal-derived collagen and gelatin (Hoang *et al.*, 2021; Kim *et al.*, 2021). The challenge of replicating the anti-ageing properties of animal-based collagen with plant-based ingredients remains a significant hurdle, particularly for premium skincare lines targeting halal-conscious consumers.

Similarly, in hair care, animal-derived keratin has been shown to repair severe hair damage due to its protein structure, which is closely aligned with human hair. Research suggests that animal keratin helps restore damaged hair by penetrating the hair shaft, strengthening the hair fibres, and improving elasticity (Qin *et al.*, 2022; Basnaz & Ferraro, 2024). For Muslim consumers, the halal status of keratin is crucial, as it must be derived from halal animals and processed by Islamic law. The need for halal certification makes animal keratin less accessible to a significant portion of the market, prompting the search for plant-based alternatives. Plant-based proteins from seeds, legumes, and oatmeal offer conditioning benefits but do not match animal keratin's deep hair repair capabilities (Qin *et al.*, 2022). While vegan keratin alternatives may be acceptable within the halal market, they are not yet as effective in hair restoration, which may limit their appeal to consumers seeking high-performance products.

Furthermore, carmine, a red colourant derived from crushed beetles, provides high colour intensity and durability in cosmetic products such as lipstick (Mahyeddin, 2020; Cristiano & Guagni, 2022). From a halal perspective, the use of carmine is problematic as it is derived from insects, which may not be acceptable in halal-certified cosmetics, mainly if they are not processed according to Islamic standards (Hussaini *et al.*, 2021). Vegan alternatives like beetroot powder, hibiscus extracts, and mica powder, which are more easily halal-certified, offer cruelty-free and environmentally friendly alternatives. However, these vegan colourants often fail to provide the same vibrancy or long-lasting intensity as carmine, challenging manufacturers to meet halal standards and consumer expectations for high-pigment formulations (Abrar *et al.*, 2024).

4.2 Cost implications of animal-based vs. vegan ingredients

Cost analysis reveals that animal-based ingredients are more expensive, primarily due to the extraction and processing techniques involved. For instance, animal collagen and keratin production often require more complex and resource-intensive methods, resulting in higher costs for manufacturers and consumers (Hussaini *et al.*, 2022). However, the additional cost of sourcing halal-certified animal-derived ingredients can increase the overall expense. Halal certification often requires additional inspections, audits, and compliance with specific slaughter and processing methods, which adds a layer of cost to the production process (Shabbir *et al.*, 2022). Consequently, many consumers turn to plant-based alternatives as a more cost-effective option.

Vegan alternatives, by contrast, are typically less expensive to produce due to the abundance and lower processing costs of plant-based sources. Ingredients like agar and carrageenan, derived from seaweed, are relatively inexpensive and more accessible for halal certification as they do not involve any animal-based sources (Hoang *et al.*, 2021). However, achieving comparable stability or texture with plant-based ingredients may require adding other materials, which could lead to higher overall production costs despite the lower base cost of plant ingredients (Lestari *et al.*, 2019).

For example, although plant-based gelatin substitutes such as agar may be more affordable, their ability to effectively mimic the moisturising properties of animal gelatin may necessitate additional ingredients or more complex formulations, which could increase the cost of the final product (Kim *et al.*, 2021). This cost trade-off becomes particularly relevant for high-end products targeting halal-conscious consumers, who may seek vegan formulations that are both affordable and compliant with halal guidelines.

4.3 Ethical and sustainability considerations

One of the most significant drivers for adopting vegan alternatives in cosmetic formulations is the growing emphasis on sustainability, ethical sourcing, and halal certification. Animal-derived ingredients, such as collagen and carmine, raise ethical concerns about animal welfare, as their production often involves intensive farming practices (Visser, 2023). Moreover, the environmental impact of sourcing animal-derived ingredients and the increased consumer demand for cruelty-free products has prompted many companies to seek plant-based alternatives (Ajayi *et al.*, 2024; Sasounian *et al.*, 2024). For Muslim consumers who adhere to halal principles, ethical concerns extend beyond animal welfare to the necessity for ingredients to be sourced and processed consistent with Islamic law (Sugibayashi *et al.*, 2019; Abrar *et al.*, 2024).

Vegan ingredients, by contrast, are generally more sustainable and ethically sourced, as they do not involve animal exploitation and often have a lower environmental footprint (Shenk, 2022; Sasounian *et al.*, 2024). These ingredients are inherently compatible with halal standards and can be marketed as cruelty-free and eco-friendly alternatives. For example, plant-based colourants such as beetroot powder and hibiscus extracts offer a cruelty-free alternative to carmine and provide similar colouration benefits without the ethical

concerns associated with animal-based products (Mahyeddin, 2020; Abrar *et al.*, 2024). Halal-certified, plant-based ingredients align with Muslim and non-Muslim consumers' ethical and sustainability values, making them an attractive option in the market.

5. Conclusion

In conclusion, vegan ingredients have significant potential to align with the core principles of halal cosmetics, emphasising purity, ethical sourcing, and environmental sustainability. While traditional animal-based ingredients like collagen, gelatin, keratin, and carmine remain effective, vegan alternatives emerge as ethical, cruelty-free, and viable substitutes. These plant-based options not only address concerns of animal exploitation but also cater to the growing demand for health-conscious and environmentally responsible products.

Although vegan alternatives may not always replicate the performance of animal-derived ingredients, advancements in formulation and biotechnology are narrowing this gap. Manufacturers can focus on improving the efficacy of vegan ingredients through innovation. At the same time, halal certification bodies should collaborate with them to establish clear, inclusive standards that cater to both vegan principles and religious requirements. Manufacturers and certifiers must work together to address challenges such as ingredient sourcing and production methods to ensure compliance with halal standards. Moreover, the global appeal of vegan halal products extends far beyond Muslim consumers. With increasing consumer awareness about sustainability, cruelty-free sourcing, and clean beauty, non-Muslim markets are also drawn to these products. As the demand for ethical and sustainable cosmetics grows, manufacturers should view vegan halal products as a strategic opportunity to tap into both Muslim and non-Muslim demographics.

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Conventional Blending Chitosan Lignin Nanocomposites Hydrogel (CsLNPs) for food coating application

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Abstract

Despite the importance of bio-based materials for food coatings, studies on how LNPs enhance thermal stability, swelling behaviour, and barrier properties remain limited, creating a gap in sustainable food preservation solutions. This work successfully prepared the lignin chitosan nanocomposites hydrogel (CsLNPs) via a conventional, cost-effective blending method. The incorporation of LNPs into Cs hydrogels was confirmed via FTIR, showing interactions between LNPs' -OH groups and Cs' -NH2 groups, with peak shifts at 3400–3200 cm^{-1}. Thermal analysis revealed decomposition temperatures (T_{max}) of 285–290°C, with T10% >170°C and >24% residue at 800°C. Glass transition temperatures (Tg) ranged from 143–154°C. LNPs initially improved thermal stability, although higher loading caused agglomeration, reducing performance. LNPs-Cs hydrogels displayed insolubility in non-polar solvents due to their inherent structure, while increasing lignin loading (5–20%) enhanced water absorption and swelling, slowing fruit rotting. This demonstrated improved moisture and oxygen barrier properties. The findings highlight CsLNPs as a sustainable, effective food coating, reducing waste, promoting eco-friendly packaging, and advancing bio-based solutions for food technology.

1. Introduction

In recent years, there has been a growing global emphasis on sustainable consumption and production practices to address pressing challenges such as food security (Vågsholm *et al.*, 2020) and environmental sustainability. Among various strategies, developing biocompatible materials for food packaging (Rai *et al.*, 2017) and coating applications (Rafiae *et al.*, 2024) stand out as a pivotal area for innovation. Biopolymers derived from renewable resources offer promising solutions due to their biodegradability, low environmental impact, and potential to enhance food preservation and safety (Munteanu & Vasile, 2020). This activity is particularly crucial in improving the safety and quality of perishable foods during storage and transportation, thereby addressing food security challenges. As regulatory frameworks worldwide increasingly prioritise sustainable packaging materials and food safety standards, biopolymers offer compliant solutions that align with consumer preferences for eco-friendly products.

Chitosan (Cs) is a natural polysaccharide derived by the partial deacetylation of chitin, a structural component found in crustaceans' exoskeletons (Nasrollahzadeh *et al.*, 2021). Their integration into nanocomposite hydrogels presents a compelling approach towards sustainable food coating applications. Cs, known for their antimicrobial properties and biocompatibility, can prolong the shelf-life of perishable foods by inhibiting microbial growth (Souza *et al.*, 2020). With its robust structural properties and antioxidant capabilities, lignin complements Cs by enhancing mechanical strength and providing additional barrier protection against oxygen and moisture. These allow for improved compatibility with various polymeric matrices, expanding the scope of CsLNPs composite materials across diverse fields, including wastewater treatment (Sohni *et al.*, 2019), food packaging (Rai *et al.*, 2017), and tissue engineering (Islam *et al.*, 2020). Moreover, amidst global challenges related to food security, where efficient food preservation and distribution are crucial, the development of CsLNPs holds promise in enhancing food safety and extending shelf life. By exploring the formulation and performance of CsLNPs as food coatings, this research contributes to the broader objective of achieving sustainable food systems that are resilient, resource-efficient, and environmentally responsible.

Chemical approaches like cross-linking and polymerisation involve potentially toxic agents and raise environmental concerns. They also present difficulties in achieving uniform particle sizes. Self-assembly poses challenges in maintaining consistent particle size and scalability (Hussin *et al.*, 2022). Solvent-based methods, such as solvent shifting and acid

precipitation, require careful solvent selection and may contribute to environmental and safety issues (Hussin *et al.*, 2022). Zhang *et al.*, 2021, reported that carbon dioxide antisolvent precipitation demands specialised equipment and introduces safety considerations due to high-pressure CO2. Lastly, physical methods like ultrasonication may encounter issues such as agglomeration and difficulties in achieving uniform particle sizes, with ultrasonication potentially generating heat that can alter Nanolignin properties (Tang *et al.*, 2020).

These disadvantages underscore the need for alternative, more efficient methods in LNPs preparation. Moreover, assessing the hydrogel's biocompatibility may involve complex and time-consuming biological assays, introducing challenges in standardisation and reproducibility. The analysis of degradation properties could be hindered by the diverse environmental conditions encountered during degradation testing, making it difficult to draw conclusive comparisons. These disadvantages underscore the need for careful consideration and standardised methodologies when investigating the influence of Nanolignin content in nanocomposite hydrogels.

This work focuses on obtaining Cs lignin nanocomposite hydrogels (CsLNPs) with the lignin nanoparticles (LNPs) extracted from the Empty Fruit Bunches (EFB) of oil palm. The LNPs were prepared using the high shear homogenisation method to increase dispersion and thermal resistance, while Cs/LNPs were mixed under an ambient environment using a conventional blending technique. To our knowledge, this is the first instance of developing a simple nanocomposite hydrogel that significantly extends the shelf life of fruits and vegetables by preventing oxidation and rapid deterioration, thus addressing the growing demand for eco-friendly coating solutions. Using shear homogenisation—which applies mechanical shear forces through high-speed rotating blades or narrow gaps—effectively reduces particle size and creates emulsions.

2. Materials and methods

2.1 Materials

Oil Palm Empty Fruit Bunch (EFB) supplied by the LignoTek Lab, School of Chemical Sciences, USM. Sodium hydroxide (NaOH, 30%) from Progressive Scientific Sdn. Bhd. Sulfuric acid (H2SO4, 98%) was purchased from Avantor Performance Materials Llc. Chitosan (Cs) powder was bought from Xi'an Lanshan Biotechnology Co., Ltd., While an acetic acid (CH3COOH, 2%) was supplied from QREC (ASIA) Sdn. Bhd. Distilled water and deionised water were also used in the study.

2.2 Preparation of Lignin Nano Particles (LNPs)

Lignin was extracted from the empty palm oil fruit bunch (EFB) using a soda pulping technique. The empty fruit bunch (EFB) was treated with 30% sodium hydroxide (NaOH) at 170°C for 3 hours. The resultant black liquor was vacuum-filtered to remove excess pulp residues (degraded carbohydrates and inorganic ions). The lignin was separated by progressively acidifying the black liquor to pH 2 with 20% v/v H2SO4 solutions. The precipitated lignin was centrifuged at 3500 rpm for 10 minutes to remove excess water, then dried in an oven at 45°C for 48 hours to remove moisture before being ground to a fine brown powder.

About 4 g of soda lignin was soaked and dispersed in 400 mL of deionised water. Then, it was treated at four different shear speeds of the homogeniser (mechanical homogeniser, IKA T25 digital ULTRA-TURRAX, USA with IKA) for 1 hour and then was sonicated using an ultrasonic bath sonicator for 10 minutes. Finally, the samples were dried using a freeze-dried method at around 45°C. Table 1 summarises a series of LNPs prepared at different homogeniser speeds.

Table 1: Summary of the preparation of LNPs for four different homogeniser speeds

Sample designation	Homogeniser speeds (rpm)	pH	t(min)
LNPs6	6400	2	60
LNPs8	8400	2	60
LNPs10	10400	2	60
LNPs12	12400	2	60

2.3 Preparation of lignin chitosan nanocomposites hydrogel (CsLNPs)

About 10 g of Cs was individually dissolved in an acetic acid solution (2%, 90 mL) with stirring at 500 rpm for 3 hours to yield the Cs solution. Simultaneously, LNPs 0.5 g was dissolved in deionised water (9.5 mL) at 500 rpm for 3 hours to produce the LNPs solution (5 wt%). The Cs solution (10 g) and Nanolignin solution (10 g) were mixed and stirred at 1000 rpm for 3 hours. Then, the homogeneous mixture was cast into a petri dish and thawed at room temperature for 3 days. The CsLNPs series are shown in Table 2.

Table 2: Summary of the preparation of CsLNPs hydrogel series

Hydrogel Sample	**Mass of Cs (g)**	**Mass of LNPs (g)**	**LNPs Loading (%)**
Cs	10.0	0	0
CsLNPs 5%	9.5	0.5	5
CsLNPs10%	9.0	1.0	10
CsLNPs20%	8.0	2.0	20
NLPs	0.0	10.0	100

2.4 Characterisation

2.4.1 Fourier Transform Infrared-Attenuated Total Reflectance Spectroscopy (FTIR-ATR)

The FTIR spectra of LNPs and CsLNPs were obtained using Perkin Elmer System 2000 (Perkin Elmer Norwalk, USA) at the frequency range of 4000 cm^{-1} to 400 cm^{-1} with a resolution of 8 cm^{-1} and 32 scans.

2.4.2 Ultraviolet-Visible Spectroscopy (UV-Vis)

UV-Vis spectra were obtained using SHIMADZU UV-Vis-2600i Spectroscopy (SHIMADZU, USA). Samples were placed in a cuvette calibrated using distilled water as a blank solution, and the absorbance and transmittance over a wavelength range of 100 to 1000 nm were measured.

2.4.3 Thermal properties

A Perkin Elmer TGA STA 6000 (TA Instruments, New Castle, USA) thermogravimetric analyser was used for thermogravimetric analysis (TGA). Nitrogen was used as a purge gas with a 40 mL/min flow rate. About 10 mg of samples were heated at 10 °C/min from 25 °C to 800 °C.

Differential Scanning Calorimetry (DSC) analysis was used to analyse the sample glass transition temperature (Tg) and heat capacity variations using DSC Netzsch 3500 Sirius (Netzsch, Germany). About 10 mg of samples were heated at 10 °C/min from 25 °C to 200 °C under a 25 mL/min nitrogen flow rate.

2.4.4 Chemical stability

A solubility test was conducted by dissolving each of the 5 mm x 5 mm samples in 10 mL of 1.0M sulfuric acid (H_2SO_4), 1.0M acetic acid (CH_3COOH), 1.0M sodium hydroxide (NaOH), 1.0M ammonia (NH_3), chloroform, dimethylformamide (DMF), and hexane, which represent the respective strong acid, weak acid, strong base, weak base, protic, polar aprotic, and non-polar solvents under ambient condition.

The degree of swelling was determined using the swelling test. The mass of 5 mm x 5 mm of dry samples were accurately recorded (Wtdry) and immersed in deionised water (pH = 7.2) at 25°C. The wet mass was recorded (Wt_{wet}) each hour until 25 hours. The degree of swelling was calculated according to Eq. 1:

$$\text{Degree of Swelling (\%)} = \frac{Wt_{wet} - Wt_{dry}}{Wt_{dry}} \text{ x } 100\% \qquad \text{Eq. 1}$$

where, Wt_wet represents the final mass of the sample after immersion while Wt_dry represents the initial mass of the sample before immersion.

2.4.5 Pre-coated banana analysis

To assess the effectiveness of Cs hydrogel, LNPs hydrogel, and varying concentrations (5%, 10%, 20%) of the CsLNPs hydrogel as fruit preservation and in extending the shelf-life and preserving the quality of unripe bananas, a controlled experiment was conducted. Unripe banana samples were divided into groups: one uncoated (control) and others coated with the specified hydrogel formulations using the dip coating method, ensuring uniform coverage. The coated bananas were then stored under controlled environmental conditions, and the colour and appearance change pictures were taken daily over 7 days of deterioration. The study aimed to evaluate which hydrogel formulation, if any, effectively delayed the ripening process and maintained banana quality over time.

3. Results and discussion

3.1 Fourier Transform Infrared-Attenuated Total Reflectance Spectroscopy (FTIR-ATR)

The FTIR spectra of the LNPs series prepared at different homogeniser speeds in the range of 500-4000 cm^{-1} are presented in Figure 1. The characteristic absorption bands for LNPs were indicated by the presence of peaks at the 3421 cm^{-1} (O-H stretching), 1600–1500 cm^{-1} (skeletal vibrations of lignin aromatic rings) and 1107 cm^{-1} (aromatic and ether stretching) (Yaqoob *et al.*, 2021). The spectra demonstrated that preparing LNPs at different homogeniser speeds did not alter the lignin functional groups. This finding is consistent with Rahman *et al.*, 2018, who reported that the functional groups of nanosized lignin are similar to those of pristine lignin. However, as the homogenisation speed increases from 6400 to 12400 rpm/h, the peaks at 3400–3200 cm^{-1} (O-H stretching), 1600 cm-1 (C-H stretching of aromatic rings), and 1212 cm-1 (C-O stretching) show decreased intensity, which is suggested to be due to the reduction of LNPs' size and increased surface interactions between LNPs. This result is consistent with the work reported by Sekeri *et al.*, 2020, which is the fragmentation and alteration of lignin's molecular structure, creating smaller units that expose more aromatic rings that enhance the absorbance of LNPs spectra. The FTIR spectra of Cs hydrogel and LNPs displayed distinctive absorption bands, as shown in Figure 2.

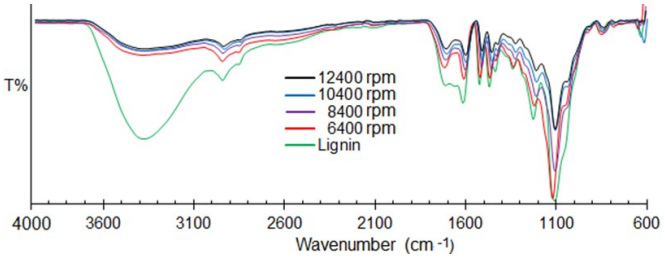

Figure 1: FTIR spectra of LNPs series prepared at different homogeniser speeds.

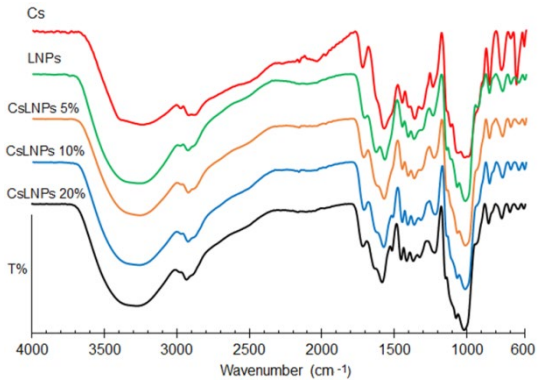

Figure 2: FTIR spectra of CsLNPs hydrogel series.

Cs exhibits a broad absorption band at around 3400-3200 cm^{-1} (stretching vibrations of O-H and N-H groups), 2920-2850 cm^{-1} (C-H stretching of methylene groups) and 1577.38 (amide II, N-H bending vibrations) which are characteristic of the Cs polymer backbone (Mohamad Zharif *et al.,* 2021). Introducing LNPs in Cs hydrogel in the form of CsLNPs hydrogel series exhibit shifted distinctive absorption bands at 3289.86 cm^{-1} (broad O-H and N-H stretching), 2932.27 cm^{-1} (C-H stretching), 1634.05 cm^{-1} (amide I) and 1575.63 cm^{-1} (amide II). These peak findings are consistent with what was reported by Mohaiyiddin *et al.,* 2018. These findings suggest that the -OH in LNPs interaction with $-NH_2$ in Cs hydrogel through electrostatic interaction leads to the shifted peak in the Cs LNPs hydrogel series without the disappearance of the Cs hydrogel peaks attribute. (Figure 3).

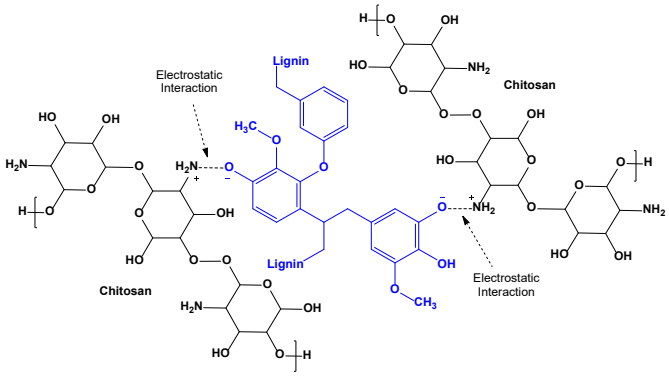

Figure 3: The electrostatic interaction between LNPs and Cs molecules.

Amino groups (-NH2) in Cs hydrogels can be protonated in acidic conditions, imparting a positive charge along the Cs chains, while hydroxyl (-OH) groups in LNPs deprotonated under neutral to basic conditions, giving the lignin nanoparticles a negative charge. As Cs hydrogel and LNPs were brought into contact in an aqueous environment, electrostatic interactions occurred between the positively charged amino groups on Cs and the negatively charged hydroxyl groups on lignin. These suggested that electrostatic attractions can facilitate the dispersion of lignin nanoparticles within the Cs hydrogel matrix, especially at lower concentrations of LNPs. As the loading of hydroxyl lignin nanoparticles increases, positively charged Cs hydrogel can become overwhelmed by the negatively charged LNPs and increase the tendency for LNPs to aggregate or agglomerate. This leads to phase separation within the Cs hydrogel matrix, where regions enriched with LNPs form distinct clusters or domains. Later, this creates stress concentration points or weak interfaces within the CsLNPs hydrogel matrix, which affects its overall thermal and mechanical stability.

3.2 Ultraviolet-Visible Spectroscopy (UV-Vis)

UV-Vis analysis studies the interactions between LNPs and Cs molecules within the CsLNPs hydrogel series, especially the bonding between the hydrogel matrix. Figure 4 shows the loading-dependent spectra of CsLNPs hydrogel measured in distilled water at room temperature.

LNPs show a prominence absorbance peak at 285 nm and a weak shoulder at 280 – 320 due to their aromatic ring structures and conjugated double bonds. Cs shows a broad and weak shoulder at the wavelength 280 – 320 nm due to partially deacetylated chitin forming carbonyl-containing degradation products (Rai *et al.,* 2017). The absorbance peak was less intense in Cs hydrogel due to it lacking conjugated double bonds, which had strong n→π* and π→π* electronic transitions that absorb UV light.

The increasing 5% LNPs loading results in more LNPs within the CsLNPs hydrogel matrix. This result suggested that the overall absorption of light passing through the CsLNPs hydrogel matrix was enhanced (Rai *et al.,* 2017). This result was consistent with Beer's Law, which states that absorbance is directly proportional to the concentration of the absorbing species—further increasing to 20% LNPs loading results in increasing absorbance proportionally. The formation of charge transfer complexes between lignin and Cs could also increase absorbance and intensify the peak at the wavelength 285 nm.

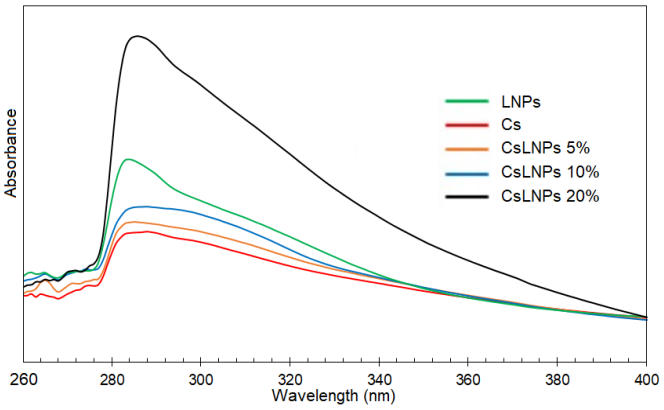

Figure 4: UV-Vis spectra of CsLNPs hydrogel series.

As the loading of hydroxyl lignin nanoparticles increases, positively charged Cs hydrogel increases, leading the LNPs to aggregate or agglomerate, increasing absorbance.

3.3 Thermal properties

TGA provides valuable information on thermal stability, decomposition kinetics, and material composition by measuring mass changes with temperature, making it particularly useful for assessing CsLNPs hydrogel series degradation. Figure 5 shows that the CsLNPs hydrogel series exhibited a one-step degradation with an onset temperature of around 100 °C to an end-set temperature of around 400°C. In comparison, LNPs hydrogel showed a two-step degradation: the first at 310°C and the second was above 450°C. LNPs hydrogel has demonstrated higher thermal decomposition temperature (T_{max}) than Cs hydrogel due to the complexity of lignin molecules, which is cross-linked aromatic or branched with strong covalent bonds; in contrast, Cs hydrogel has a more linear structure with less cross-linking, leading to lower thermal stability. Besides that, the presence of aromatic rings in lignin molecules causes slower and more gradual mass loss and withstand higher temperatures before breaking down, leaving higher char once degradation ends at 800 °C. Cs decomposed more rapidly at lower temperatures due to their less stable amine and hydroxyl group structure, which often degrades as volatile compounds like water (Vasilev *et al.,* 2019). Table 3 shows that Cs hydrogel has about 10% less char than LNPs hydrogel.

Increasing LNPs loading from 10% to 20% in CsLNPs hydrogels shows that T_{max} does not significantly reduce thermal decomposition. This result suggested that complex aromatic structures and strong covalent bonds in lignin molecules are inherently thermally stable, preventing a substantial decrease in the thermal degradation temperature. Table 3 also proved that increasing LNPs loading promoted higher char formation during decomposition, which protects against further degradation. Besides that, T_{max} contributed to the Cs fraction; as the lignin loading increased, which led to more char, the Cs fraction decreased, leading to a decrease in T_{max}. Therefore, CsLNPs hydrogels exhibit synergistic effects with component fraction in the hydrogel, enhancing the overall thermal stability beyond what would be expected from simply increasing the amount of lignin alone.

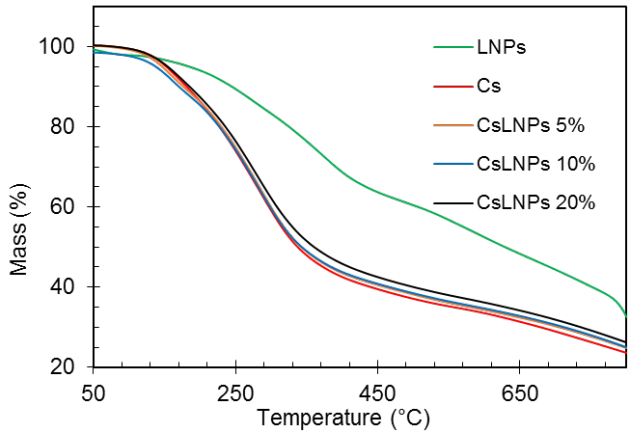

Figure 5: TGA and DTG curves for CsLNPs hydrogel series.

The DSC curves, recorded on the second heating cycle (Figure 6), determine the CsLNPs chain mobility. The shift in temperature was related to the interactions between the Cs matrix and the lignin nanoparticles. The traces of the Cs molecules in Cs hydrogel 0% were seen at the first endothermic peak, at 110–130°C, which was attributed to absorbing moisture. In contrast, Cs's glass transition temperature (Tg) is 120°C. This value is slightly lower than Cs thin film (Tg=140 - 150°C), which has been reported by Dong *et al.* 2004, due to Cs hydrogel having a strong affinity towards water (water-polymer interaction). Their endotherm is usually related to water's evaporation, which was observed to be lower than Cs thin films. Introducing 5% LNPs in CsLNPs hydrogel using a blending technique shows Tg increases around 30°C. This suggested that the 5% LNPs increase the rigidity of the Cs backbone while restricting the mobility of Cs molecules to soften at higher temperatures (Noor *et al.,* 2020).

Table 3: TGA and DTG results for CsLNPs hydrogel series

Hydrogel Sample	**T_{10}**	T_{max}	**Residue at 800 ˚C**
Cs	180.5	290.4	23.6
CsLNPs 5%	175.5	290.5	24.8
CsLNPs 10%	170.8	285.8	25.0
CsLNPs 20%	185.5	285.5	26.2
LNPs Hydrogel	245.5	365.5	32.5

Further increasing to 20% LNPs in CsLNPs hydrogel, the thermal stability of the CsLNPs hydrogel series did not continue to increase. Instead, it has a negative effect, causing the Tg to drop 10°C to 143°C. This result suggested that the LNPs may start to agglomerate, leading to poorer dispersion within the Cs matrix while increasing the free volume within the polymer matrix, which can facilitate molecular motion and lower the Tg. The initial increase in Tg at 5% LNPs can be explained as well-dispersed LNPs, meaning they are uniformly distributed throughout the Cs hydrogel matrix. This increase facilitated a good interaction between LNPs and Cs chains, restricting chain mobility. Janik *et al.,* 2021, reported that decreasing free volume significantly increases the Tg.

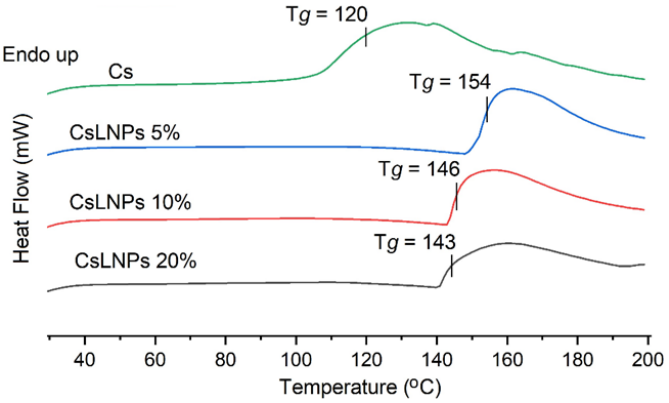

Figure 6: DSC curves for CsLNPs hydrogel series.

This result was contrary to further increasing LNPs loading, which induced LNPs to agglomerate, creating non-uniform regions to lead aggregates. In contrast, the increased free volume allows molecular motion and decreases Tg. Although Tg showed a decreasing trend, this was not always consistent with the decreasing trend in materials stability. Figure 7 shows the correlation between chain mobility and thermal decomposition temperature of the CsLNPs hydrogel series.

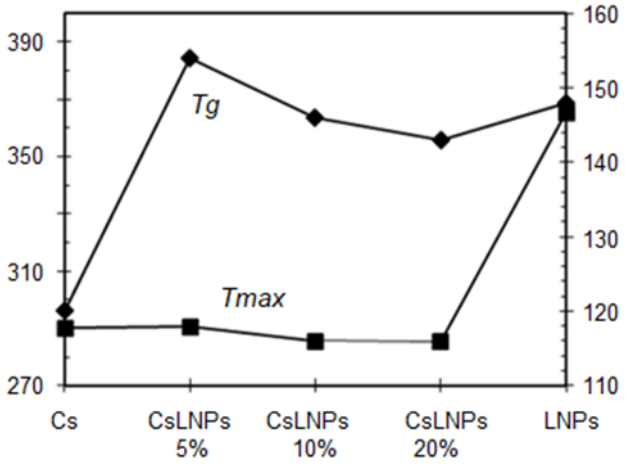

Figure 7: Correlation between Tg and T_{max} CsLNPs hydrogel series.

Introducing 5% LNPs in CsLNPs hydrogel using a blending technique shows the increases in Tg but on T_{max}. This result suggested that T_{max}, the temperature at which significant decomposition of the hydrogel occurs, is primarily governed by the thermal properties of lignin. The addition of LNPs does not significantly alter the overall thermal stability of the hydrogel and initially ensures a homogeneous distribution of nanoparticles, which allows lignin to exert its reinforcing effects evenly throughout the hydrogel matrix, influencing the mechanical and thermal properties consistently; hence, the T_{max} remains unchanged. At higher loadings of LNPs, like 10%, agglomeration or uneven dispersion of LNPs can exacerbate phase separation and reduce the effectiveness of lignin in reinforcing the hydrogel structure. This uneven distribution can lead to inconsistent thermal properties across the hydrogel, affecting Tg and T_{max}.

3.4 Chemical stability

To be used in food coating applications, determining the chemical stability of CsLNPs hydrogel series in various solvents is crucial due to the chemical resistance and durability of materials, solubility and interaction materials with food components, food safety and shelf life, and fulfilment of the regulatory compliance. These results help optimise the hydrogel for real-world food applications, ensuring it meets industry standards and consumer expectations. The solubility behaviour of the CsLNPs hydrogel series compared to the results of the LNPs hydrogel and Cs hydrogel can be found in Table 4.

LNPs hydrogel is fully soluble in strong bases, weak acids, and weak bases, except for the strong acids. Zhang *et al.,* 2021, reported that Cs-lignin composites resisted strong acids. On the other hand, Cs hydrogel was partially soluble in similar acidity/basicity environments. This result is due to the amino groups ($-NH_2$) in Cs molecules either becoming protonated to form $-NH_3^+$ ions at pH<6 or deprotonated at pH>7, resulting in the formation of $-NH_2$, which leads to increased or decreased electrostatic repulsion between chains, which helps to dissolve/aggregate the Cs in the acidic/basic solution—introducing LNPs hydrogel in a Cs hydrogel system through conventional blending, resulting in the CsLNPs hydrogel series exhibiting partial solubility. Further, increasing LNPs loading does not change partially soluble behaviour. This result suggested that the composite hydrogel does not dissolve as completely as lignin hydrogel does on its own but behaves more like Cs regarding solubility. As the system molecular weight of Cs increases due to the interaction with LNPs molecules, chain length and entanglement may increase, leading to more significant aggregation and lower solubility.

LNPs and CsLNPs hydrogel series demonstrate insoluble behaviour in non-polar solvents due to their inherent chemical structure and the nature of non-polar solvents. Note that the hydroxyl (-OH) groups and amino groups ($-NH_2$) can form hydrogen bonding and be protonated. Non-polar solvents lacking in polarity characteristics (partial positive or negative charges) form hydrogen bonds or engage in this interaction to dissolve Cs and lignin segments (Mohaiyiddin *et al.,* 2018). Almost a similar reason can be applied to the polar aprotic solvent which has been utilised. Thus, it can be justified that using water, ethanol, and acetic acid is most suitable in the hydrogel preparation process to meet the requirements of regulatory agencies for green materials. Due to the water existing in the air as a moister, swelling tests are essential for determining the chemical stability of CsLNPs hydrogel series to provide insights into moisture control, structural integrity coating material, compatibility with food environments, process optimisation, and safety. Figure 8 shows swelling result of CsLNPs hydrogel series in water for 25 hours.

The characteristic of Cs hydrogel swelling degree has been demonstrated as the water uptake rapidly raised during the first 4 hours. This result is due to the efficiency of hydrophilic (hydroxyl, -OH) groups in Cs molecules, which quickly attract water to be absorbed. Then, the intrinsic porous structure of the CsLNPs hydrogel frameworks facilitates the capillary action, which allows water molecules to penetrate the network quickly during the initial phase, causing the hydrogel to swell rapidly. After the initial rapid swelling, at the 5th hour, the hydrogel reaches a saturation point, indicating that water molecules fully occupy the internal hydrophilic sites. At this point, the Cs hydrogel framework reaches a state of equilibrium where the osmotic pressure inside the hydrogel balances with the external water pressure through the hydrogen bonding and van der Waals forces, stabilise the hydrogel structure, preventing further water uptake from maintaining a constant degree of swelling.

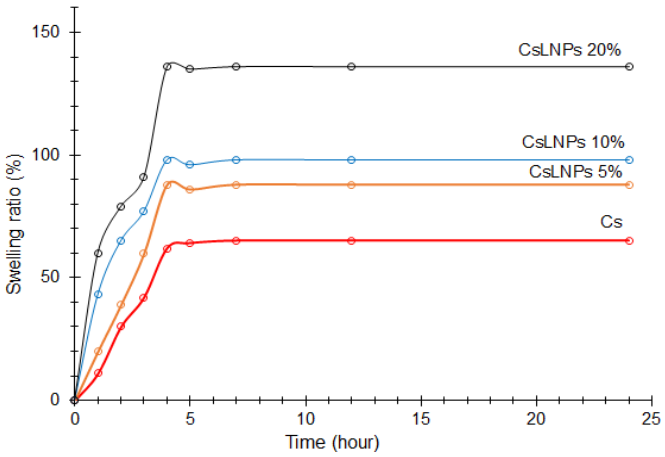

Figure 8: Swelling result of CsLNPs hydrogel series in water for 25 hours.

The increased lignin loading from 5% to 20% in the CsLNPs hydrogel series has significantly increased the swelling. This result suggested that the nature of lignin (-OH group) increases the overall hydrophilicity of the hydrogel, which enhances an ability to absorb and retain more water molecules, leading to increased swelling. Besides, with higher lignin content, the hydrogen bonds become more efficient in creating a more open hydrogel framework. This increases the free volume or spacing between Cs molecules and a higher swelling (Mohaiyiddin *et al.,* 2018). Therefore, as the water absorption capacity is maximised in higher lignin loading, the equilibrium state is also maximised before further expansion is prevented. The results conclude that the CsLNPs hydrogel series demonstrate that the maximal loading of NLPs applied maximal swelling behaviour, which indicates good green coating barrier

Table 4: Solubility of CsLNPs hydrogel series.

Hydrogel Samples	H_2SO_4 Strong acid	NaOH Strong base	AcOH Weak acid	NH_3 Weak base	$CHCl_3$ Polar protic	DMF Polar aprotic	Hexane Non-polar
Cs	±	±	±	±	±	-	-
CsLNPs 5%	±	±	±	±	-	-	-
CsLNPs 10%	±	±	±	±	±	-	-
CsLNPs 20%	±	±	±	±	±	±	-
LNPs	-	+	+	+	-	+	-

soluble: +, partially soluble: ±, insoluble: -

properties, which is essential for extending the shelf life of food products at the same time easily be removed by rinsing with water tap.

3.5 Pre-coated banana analysis

In this segment, the evaluation of pre-coating fruit shelf-life critically examined the CsLNPs hydrogel series to ensure that the coating process meets quality standards, such as uniformity, thickness, and adherence (Munteanu & Vasile, 2020). The coating provides a barrier against moisture loss, oxidation, and microbial growth. The results stemmed from a 7-day observation of bananas treated with the CsLNPs hydrogel solution, illustrated in Figure 9.

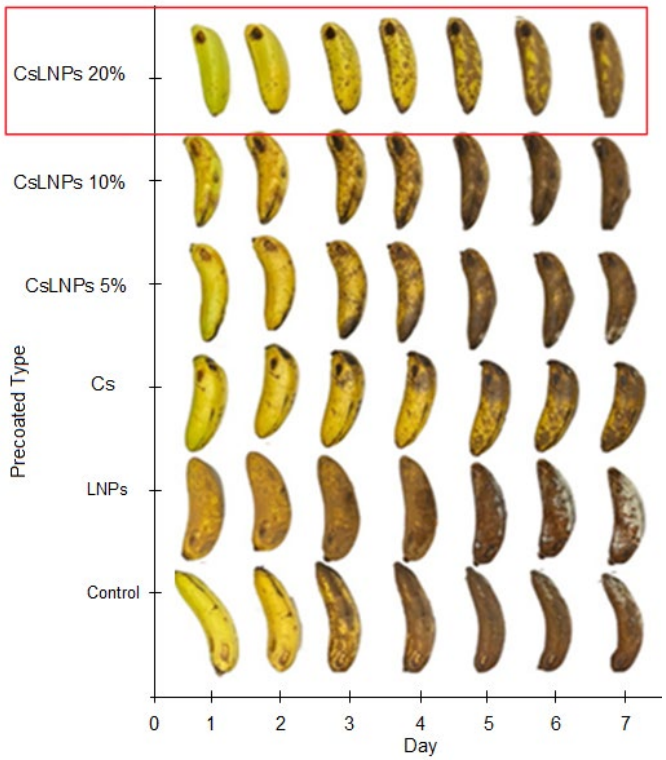

Figure 9: Pre-coated banana shelf-life analysis of CsLNPs hydrogel series.

Pre-coated bananas with LNPs hydrogel demonstrate faster deterioration and mould growth than uncoated bananas. This result suggests that abundant hydroxyl groups in the lignin molecule structure increase moisture retention on the banana's surface (acting as a nutrient source), creating a conducive environment for certain fungi (Souza *et al.,* 2020). Although lignin has antimicrobial properties, it is not strong enough to effectively prevent mould growth, especially in high moisture levels. On the other hand, Pre-coated bananas with Cs hydrogel demonstrated rotting without mould growth due to their antimicrobial properties, which can inhibit the growth of moulds/pathogens by disrupting microbial cell membranes and interfering with microbial metabolism. Besides that, Cs form a more effective barrier against moisture/oxygen and help to regulate moisture more effectively than lignin.

Introducing 5% of LNPs in CsLNPs hydrogel might minimally contribute to the overall properties of the hydrogel. The small amount of LNPs suggested slightly altered the barrier and antimicrobial properties by disrupting the chitosan matrix, leading to faster deterioration than Cs and making it less effective in mould growth. As the LNPs loading increased to 10%, it still demonstrated some deterioration, further reducing the mould growth, suggesting that due to the contribution of enough electrostatic interaction between LNPs and Cs in the CsLNPs hydrogel matrix.

The increases in lignin loading from 20% in the CsLNPs hydrogel series exhibit a slower rotting process. This result suggested that the lignin molecules are hydrophobic, and their integration into the Cs matrix enhanced the effective barrier properties against moisture and oxygen. Next, oxygen permeability is reduced, the respiration rate of the bananas slows down, and the ripening/ rotting process is delayed (Munteanu & Vasile, 2020). CsLNPs20% hydrogel demonstrated almost similar rotten performance to pure Cs hydrogel, indicating a balanced and effective combination of chitosan and lignin properties. Besides that, the mechanical strength and stability of CsLNPs20% molecular framework are enhanced due to more hydrogen bonding interaction between –OH and NH_2 group in lignin Cs hydrogel. The uniformity of coating assisted in ensuring consistent protection across the entire surface of the banana. The enhancement of mechanical strength in hydrogel molecular framework well-adhered with thermal stability. This result highlights the importance of selecting appropriate coating materials based on their interaction with food products and protective capabilities.

4. Conclusion

The CsLNPs were successfully prepared via a conventional blending method, highlighting the feasibility of integrating lignin nanoparticles (LNPs) into Cs hydrogel matrices to enhance thermal stability and coating properties. Detailed characterisation showed that LNPs interact with chitosan hydrogel through hydrogen bonding and electrostatic, as evidenced by FTIR spectroscopy. The thermal stability analysis revealed CsLNPs series with single-stage decomposition event and high T_{max} ranging from 285°C to 290°C, indicating their potential to withstand processing and storage conditions. However, some limitations were identified in this study. Introducing more than 10%wt LNPs induced agglomeration and uneven dispersion within the CsLNPs matrix. This agglomeration was initially beneficial by increasing thermal stability, but once a threshold was exceeded, further lignin loading reduced the overall thermal stability. Therefore, the matrix's degree of dispersion and uniformity should be further optimised in future studies to minimise agglomeration effects, which could negatively impact the material's mechanical properties and long-term stability. Additionally, while the thermal glass transition temperature Tg correlated well with T_{max}, further investigation is needed to assess the mechanical behaviour and long-term performance under various environmental conditions. Moreover, CsLNPs exhibited insoluble behaviour in non-polar solvents due to their inherent chemical structure, emphasising their potential as adequate moisture and toxic chemical compound barriers in food packaging. The increase in lignin loading up to 20% demonstrated enhanced water absorption capacity and slower degradation processes, highlighting the hydrophobic nature of lignin and its beneficial integration into chitosan matrices. Therefore, this work has already implemented sustainable usage and production of halal materials to address food safety and security challenges.

5. Author contributions

Conceptualization, MBHO and MNMI.; methodology, MBHO, AMAT and NNR.; software, AMAT and NNR.; validation, MBHO, MNMI and MSAS.; formal analysis, MBH Othman, AMAT and NRR.; investigation, MBHO, AMAT and NRR.; resources, MBHO.; data curation, MBHO, AMAT and NRR.; writing—original draft preparation, MBHO and AMAT;

writing—review and editing, MBHO and MSAS.; supervision, MBHO and MNMI; project administration, MBHO.; All authors have read and agreed to the published version of the manuscript.

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7. Institutional review board statement

Not applicable.

8. Data availability statement

The data are contained within this article.

9. Acknowledgements

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10. Conflicts of interest

The authors declare no conflicts of interest

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Effect of micro and nanoemulsions on wound healing: a review

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Abstract

Emulsions, categorised by their particle size into microemulsions (<100 nm) and nanoemulsions (<200 to <100 nm), hold a position of burgeoning significance in the field of wound healing. Beyond their established role in diverse medical domains, emulsions have emerged as promising agents for drug delivery with wound-healing properties. This review explores a comprehensive analysis of the available literature to shed light on the impact of micro and nanoemulsions on wound healing. Covering research articles published from 2011 to 2022, this study meticulously follows the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines while employing bibliometric analysis tools, PRISMA, and VOSviewer. Through an extensive exploration of databases such as PubMed, Scopus, and ScienceDirect, this study identifies and includes 26 articles that align with the rigorous criteria for investigating emulsions in wound healing. Our bibliometric analysis underscores 'wound healing' as the most prominent keyword in this corpus. In conclusion, this study contributes substantially to the research by combining insights into the effects of nano and microemulsions on wound healing, offering a foundation for future investigations and applications within emerging nanotechnology.

1. Introduction

Emulsions may be found in various industries, including food and beverage, pharmaceuticals, agriculture, cosmetics, and petroleum. To create an emulsion is the process of dispersing one phase into another (Akbari & Nour, 2018). Wound healing has always been a point of interest in many fields; using plant oil emulsions has demonstrated an effect on healing the wound of a zebrafish (Zain *et al.*, 2021). The kinetic stability of the emulsions is determined by the droplet size of the emulsions as well as the presence or absence of interfacial coatings that occupy the water droplets (Raya *et al.*, 2020). A systematic review will frequently compile all the data to respond to a pre-posed question. This entails locating all primary research pertinent to the review question, assessing this research, and combining all the results (Pollock & Berge, 2018). Thisanalysed. This paper thoroughly analysed papers published between 2011 and 2022, and a bibliometric analysis was conducted. From 2011 to 2022, there were 26 publications related to nano or microemulsions and wound healing, with India publishing the most literature on the topic. Institutes in Spain collaborated most on nano or microemulsions and wound healing. Furthermore, 'Wound healing' is the most often used keyword in articles within that period. As a result, this study aims to examine the available papers on nano or microemulsions and wound healing from 2011 to 2022, adopting Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) criteria and bibliometric analysis.

2. Materials and methods

2.1 Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA)

This review was performed based on the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (Page *et al.*, 2021) using the following search databases: ScienceDirect, Scopus, and PubMed. The search terms used were 'Nanoemulsions OR microemulsions', 'emulsions AND wound healing', 'microemulsions AND wound healing', and 'Nanoemulsions AND wound healing'. The searching techniques were (Terms in title, abstract, or author-specified keywords) for ScienceDirect. Besides, there were limitations in publication in terms of language, article type, and publication date. The results were restricted to literature written in English language only and research articles for ScienceDirect. The literature review covered a ten-year timeframe, from 2011 to 2022, to ensure that recent and relevant findings on emulsions, along with their regulatory aspects and effects on wound healing, were effectively highlighted. These findings are summarised in the PRISMA flow diagram shown in Figure 1.

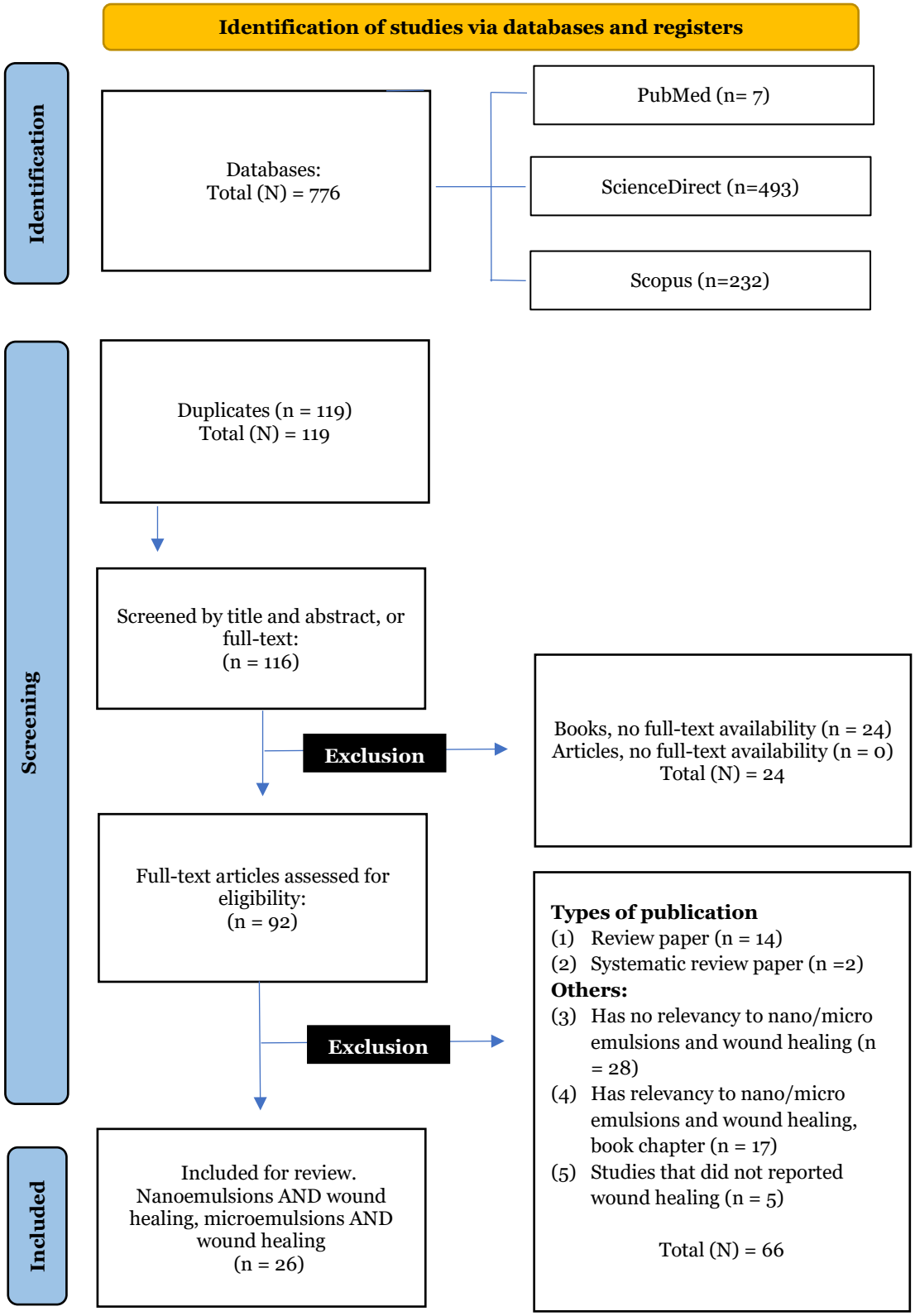

Figure 1: This illustration illustrates the PRISMA flowchart depicting identifying studies through databases and registers. The selected search engines, inclusion, and exclusion criteria led to 66 publications.

2.1.1 Eligibility and study choice

The significance of the effect of micro or nanoemulsions and rules in wound healing was thoroughly reviewed and investigated. The inclusion criteria for papers included in the review in this study included material related to the role of emulsions in wound healing, articles with full-text access or open access, publication type, English-language writing, and studies involving human subjects. The articles that were available in full text were thoroughly examined. This analysis excluded papers containing liposomes and unclassified drug subjects. Furthermore, no books, systematic reviews, review papers, case reports, or conference abstracts were included in this study. Articles that had no bearing on the functions of emulsions or their effects on wound healing were also excluded. This criterion was examined after carefully reviewing the titles and abstracts of the publications.

2.2 Bibliometric analysis

This study downloaded 776 publications on the nano or microemulsion effect in wound healing from the PubMed, Scopus, and ScienceDirect databases. This is the number of papers subjected to bibliometric analysis after being filtered by deleting duplicates, which amounted to roughly 119 documents. All articles from each database were downloaded and saved in a RIS (Research Information Systems) file format. RIS is one of the file formats that the VOSviewer, a software designed to investigate bibliometric links, can utilise and read. Some information obtained from these three databases, PubMed, Scopus, and ScienceDirect, was separated. Still, they were all connected to the nano or microemulsions and wound healing. The data retrieved from the PubMed database included the PubMed unique identification (PMID) number, publication type, publication title, author names, title of source, year published, digital object identifier (DOI) number, author keywords, and publication references. The authors' affiliation was not included in the downloaded file; it was added manually. Following that, data from the ScienceDirect database were retrieved, including publication type, title of publication, author names, title of source, year published, digital object identification (DOI) number, author keywords, and references for the paper. The authors' affiliation was not included; it was manually added for each title. Furthermore, the data gathered from the Scopus database had the title of the article, author names, identification of the source, year published, affiliation of the authors, author keywords, and references for the publication. Those files collected from the three databases were later added to an Excel sheet following Scopus format for further analysis.

3. Results and discussion

3.1 Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) main findings

In all of the included studies, the effect of micro or nanoemulsions on wound healing was acknowledged in Table 1.

Table 1: Table of main findings for all included studies

References	Study design	Population of study	Type of micro or nanoemulsions
(Okur *et al.*, 2020)	- Histopathological - Examination - *In-vitro* - 3 Months controlled	-Twenty-one Male Wistar albino rats	Fusidic acid (FA) loaded microemulsion-based gel.
(Kazemi *et al.*, 2020)	- Randomised - Histopathological - Examination - Real-time PCR - Excisional wound on the dorsal neck - of each rat - Topical application - 14 Days treatment - Controlled	- Eighty-five male Wistar rats	Nanoemulsions lavender essential oil and licorice extract
(Yousry *et al.*, 2022)	- Cytotoxicity test - *In-vivo* - Controlled - 16 Experimental runs - Histopathological - examination - Topical treatment - CLSM micrograph analysis	- Thirty-one male Wistar rats	- Collagen-loaded sunflower nanoemulsions. - Vitamin C-loaded sunflower nanoemulsions.
(Rizg *et al.*, 2022)	- Burn wound - Controlled - Topical application - 14 Days treatment - *Ex-vivo*	-Sixty-nine experimental rats	- Geranium (Gr) oil-based nanoemulsions loaded with Pravastatin PV

	- Rats were slaughtered, and abdominal skin was separated. Donor and receptor cells - An antibacterial test was performed.		
(Alhakamy *et al.,* 2022)	- Diabetic rat - Topical application - Controlled - Histopathological analysis. - Quantitative Real-Time PCR (qRT-PCR). - Histological analysis - 21 Day treatment. - Nes effect on oxidative stress analysis. - Immunohistochemical analysis of PDGF-B protein - Immunohistochemical analysis of TGF-β1	-FiftyMale Wistar rats	- Fluoxetine eco-friendly nanoemulsions (FLX-EFNE)
(Teo *et al.,* 2017)	- Topical application - Relative cell viability analysis. - Controlled - *In-vitro* cell monolayer wound scratch assay analysis. - 48 Hours treatment exposure. - The zeta potential analysis. - HPLC analysis of phenytoin-loaded alkyd nanoemulsions.	- Human adult keratinocytes (HaCaT cells)	- Phenytoin -Loaded Alkyd Nanoemulsions
(P. Alam *et al.,* 2017)	- Histopathological evaluation. - Collagen estimation - Oral administration - Controlled. - ANOVA statistical significance analysis. - 10 Day treatment.	- Twelve female Albino Wistar rats	- Clove oil nanoemulsions
(Gillespie Harmon *et al.,* 2017)	- 135 Day treatment. - 32 Wounds administered. - Controlled. - Topical treatment. - Excision of EGT. - Culture and microbial evaluation - Wound biopsy and histologic examination	- Eight healthy adult horses.	- Silver sulfadiazine cream, triple antimicrobial ointment, or hyperosmolar nanoemulsions on wound healing
(P. Alam *et al.,* 2018)	- Nanoemulsions optimisation. - Oral administration - Histopathological analysis. - Collagen determination by spectrophotometric absorbance.	-Twenty-four female Albino Wistar rats	- Eucalyptus Essential Oil Nanoemulsions
(Ahmad *et al.,*	- Controlled.	- Twenty male	- Eugenol-Nanoemulsion

2018)	- *In-vitro* drug release study. - *In-vivo* skin irritation studies. - Histological evaluation for skin. - Wound healing evaluation. - Anti-inflammatory activity. - *In-vitro* skin permeation study.	Albino Wistar rat	
(Shanmugapriya *et al.,* 2018)	- *In-vitro* cytotoxicity. - Antimicrobial activity. - *In-vitro* wound-healing assay. - Controlled.	- Four cell lines (CT26, HeLa, Panc1, and T24)	- Astaxanthin-alpha tocopherol nanoemulsions
(Akrawi *et al.,* 2020)	- Topical wound healing treatment. - *In-vitro* characterisation. - 14 Day treatment. - *Ex-vivo* Mucoadhesive Strength. - *In-vitro* Cytotoxicity Study. - Histopathological Study. - Controlled.	- Twelve adult female albino Wistar rats.	- Naringenin-Loaded Chitosan-Coated Nanoemulsions
(Farahani *et al.,* 2020)	- *In-vitro* and *In-vivo* analysis. - 22 Day treatment. - Cytotoxicity of the nanofibrous test. - Histopathological study.	- Twenty-one Male Wistar rats.	- Nanoemulsions of *Zataria multiflora*
(Back *et al.,* 2020)	- Controlled. - Skin retention or permeation assay. - Cell death by necrosis assay. - HaCaT migration assay. - Lipid peroxidation evaluation. - Histological evaluation. - 12 Day experiment.	- IAF and NEIAF. The HaCaT cell line (immortalised human keratinocytes) - Twenty-four male heterogenic Wistar rats.	- Soybean isoflavone aglycones rich fraction (IAF) incorporated into lipid nanoemulsions dispersed in acrylic-acid hydrogels
(Koshak *et al.,* 2021)	- Controlled. - *Ex-vivo* skin permeation Studies. - 14 Day treatment. - Histological examination. - RT-qPCR.	- Fifty male Wistar rats	- *Opuntia ficus-indica* Fixed Oil
(Guliani *et al.,* 2021)	- Controlled. - Bacterial growth inhibition studies. - Antibacterial activity studies with the prepared Nes. - Mechanism of bacterial killing by pure oil nanoemulsions.	- *Pseudomonas aeruginosa* bacteria.	- Citral and carvone-reduced oil
(Dolgachev *et al.,* 2021)	- Controlled. - 21 Day experiment. - Histological test.	- Eight pigs.	- Benzalkonium chloride nanoemulsions.

	- Topical burn wound. - Quantitation of soluble Mediators by enzyme. - Detection of neutrophils. - Hair follicle assessment.		
(M. S. Alam *et al.*, 2021)	- Controlled. - Antioxidant activity of Sage oil nanoemulsions. - DNA, protein, and collagen contents. - 12 Day treatment.	- Eighteen Wistar rats male	- Sage oil nanoemulsions
(Chakraborty *et al.*, 2021)	- Controlled. - Evaluation of nanoemulsions. - *Ex-vivo* permeation. - *In-vivo* evaluation. - 14 Day treatment. - Histopathology evaluation.	- Adult albino Wistar rats of either sex.	- Insulin-loaded nanoemulsions with Aloe vera gel
(Abdellatif *et al.*, 2021)	- Controlled. - *Ex-vivo* permeation. - Skin deposition. - *In-vitro* wound healing assay. - Histopathological studies.	- Human skin fibroblast cells.	- Propolis and tea tree oil nanoemulsions loaded with clindamycin hydrochloride
(Maatouk *et al.*, 2021)	- Controlled. - Encapsulation and release studies. - *In-vitro* experiment. - Cellular uptake of NPs investigation.	- HaCaT cell line (immortalised human keratinocytes)	- Sulfated alginate or polycaprolactone double-emulsion nanoparticles
(Vater *et al.*, 2022)	- The EZ4U cell proliferation assay. - The BrdU assay. - *In-vitro* wound healing assays. - *In-vitro* scratch assay. - 48-hour treatment.	- Human fibroblasts. - Human keratinocytes.	- Lecithin-based nanoemulsions
(Almukainzi *et al.*, 2022)	- Controlled. - Fourier-transform infrared spectroscopy (FTIR) analysis. - *In-vitro* Characterisation. - Transmission electron microscopy. - *In-vitro* release pattern. - Skin histological analysis. - *In-vivo* wound healing study.	- Ninety-six male Sprague-Dawley rat	- Gentiopicroside (GPS) nanosphere.
(Singh *et al.*, 2022)	- Controlled. - Permeation study. - Skin irritation test. - The hydroxyproline assay. - *Ex-vivo* permeation and retention analysis. - Histopathology.	- Female Wistar rats	- Raloxifene Nanoemulsions Gel
(Ghosh *et al.*, 2013)	- Controlled. - Antimicrobial activity.	- Twelve male Wistar rats	- Cinnamon oil (*Cinnamomum zeylanicum*) microemulsion.

	- Epithelialisation period. - Antibacterial activity. - Skin irritation assessment. - Wound healing study.		
(de Assis *et al.*, 2020)	- Controlled. - *In-vivo* pharmacological activity. - Morphological analysis. - Microbiological analysis. - 16 Day experiment. - Clinical aspects of skin wounds.	- Twenty-four male and female Swiss mice	- *Melaleuca alternifolia* essential oil (MEO) Microemulsions.
(Ryu *et al.*, 2020)	- Controlled. - *In-vitro* cell Experiment. - *In-vitro* membrane permeation experiment. - *In-vitro* skin permeation experiment. - Permeation experiments. - Effect of CoQ10 on skin regeneration.	- The HaCaT and NIH3T3 cells w	- Q10-Loaded Microemulsion

Table 1 compiles research on the effects of micro- and nanoemulsions on wound healing. Experiments were done in controlled environments for consistency. Commonly used species included Wistar rats, human adult keratinocytes, adult horses, and pigs, all under ethical guidelines. Safety measures were strictly followed before animal testing, essential before human trials. Standard procedures were used, such as acclimating samples, toxicity testing, inducing wounds, applying treatments, and observing systematically. The treatments helped heal wounds across different species, showing the beneficial effects of emulsions on various skin types. Histological analysis and permeation experiments monitored healing progress, which varied from 2 days to four months, depending on the sample and wound size. Control samples without additives were used for accurate comparison. Table 1 proves the positive effects and the future potential of micro- and nanoemulsions on wound healing.

The studies in Table 1 examine using micro and nanoemulsions for wound healing. Researchers often use methods like laboratory testing, histopathological evaluations, and animal models, particularly Wistar rats, which are common in wound healing research. These controlled settings allow detailed observations and comparisons between treated and untreated samples. Many studies explore different active ingredients, including essential oils, plant extracts, and drugs, chosen for their potential to speed up wound closure, reduce inflammation, and promote tissue repair. Researchers often assess formulations for stability, antimicrobial properties, and how well they penetrate the skin, which are critical factors for their effectiveness. Findings show improvements in wound healing with these emulsions, regardless of the specific active compounds. This indicates that the formulation method is important in making the active ingredients more effective. Histological analyses commonly demonstrate faster wound closure, increased collagen production, and reduced inflammation in treated samples. The application of emulsions remains the most common method, designed to adhere to wounds and gradually release active compounds for sustained therapeutic effects. Some studies also investigate oral administration to examine broader effects. Using both *ex-vivo* and *in-vivo* models strengthens the findings. Studies include detailed measurements like PCR immunohistochemistry, and tissue analysis to ensure accuracy. These methods provide a clearer view of how different treatments affect wounds over short and long periods. treated samples than in untreated ones. The studies cover many emulsions, from those based on plant extracts to drug-loaded formulations. This variety highlights the flexibility of micro and nanoemulsions for different types of wounds, such as burns, diabetic ulcers, and surgical incisions. Topical application remains the most common method, designed to adhere to wounds and release active compounds gradually. Some studies also investigate oral administration to examine broader effects. Using both *ex-vivo* and *in-vivo* models strengthens the findings. Studies include detailed measurements like PCR, immunohistochemistry, and tissue analysis to ensure accuracy. These methods provide a clearer view of how different treatments affect wounds over short and long periods.

Safety remains a key focus, with tests for cytotoxicity and skin irritation included to ensure the emulsions are safe. Researchers also examine factors like droplet size, zeta potential, and drug release profiles to balance effectiveness and safety. Adjustments in the formulation are ongoing, aiming to enhance therapeutic benefits while minimising risks. Animal studies and laboratory tests show potential for micro and nanoemulsions in wound care. Positive results suggest they may be suitable for human trials. Nanoemulsions, in particular, are often chosen over traditional treatments because they might offer better penetration, stability, and the ability to carry both water- and fat-soluble substances.

However, a gap remains in human clinical trials. The differences in skin structure between animals and humans mean these promising results need careful interpretation before broader use. Additionally, recent research combines natural compounds like essential oils with synthetic ingredients. This approach combines traditional medicine with modern methods. The increasing focus on essential oils in nanoemulsions for their antimicrobial and anti-inflammatory properties suggests a growing interest in natural remedies for wound care. One challenge is the variation in how nanoemulsions are prepared, which can affect reproducibility

and scalability. Standardising preparation techniques are necessary to ensure consistent results. Simplifying complex processes could make these formulations more practical for larger-scale production and clinical application.

3.2 Data extraction and synthesis of findings

In the review process, 776 publications were initially identified through searches employing specific keywords ('Microemulsions AND Wound healing', 'Nanoemulsions AND Wound healing', and 'Emulsions AND Wound healing') across PubMed, Scopus, and ScienceDirect databases. After removing the duplicates using EndNote version X20.2.1 software, 119 duplicate articles were removed—subsequent screening involved examining titles, abstracts, and full texts, excluding 24 articles. The remaining 92 publications were subjected to the eligibility criteria. Twelve articles were eliminated due to their type (comprising review papers and systematic reviews), and 28 were found irrelevant to nano or microemulsions and wound healing. Another exclusion criterion was studies that did not report on wound healing, excluding 5 studies. Seventeen publications were excluded as they pertained to book chapters and did not meet the study's criteria. Consequently, 66 publications were excluded at this stage. Ultimately, 26 articles remained eligible for analysis, focusing on the impact of micro or nanoemulsions on wound healing. These selected papers were then summarised in a table, including authors' names, publication year, study design, study population, and the effects of nanoemulsions and microemulsions on wound healing.

3.3 Bibliometric analysis results

3.3.1 Countries analysis

Figure 2, generated using VOSviewer, illustrates the analysis from 2011 to 2022. The data reveals India as the most prolific country in publishing research on micro or nanoemulsions and wound healing, contributing to 12.09% of total publications. Following closely, Saudi Arabia and China, are responsible for 10.03% and 10.03% of the publications, respectively. Noteworthy contributions also come from the United States and Egypt, constituting 7.37% and 7.96% of the publications, respectively. As highlighted in Table 2, numerous countries worldwide have significantly contributed to the research on the impact of micro or nanoemulsions on wound healing, indicating the widespread interest in this area. Figure 2 visually represents these findings, with larger bubbles denoting countries with higher publication rates. These insights are instrumental in understanding the intricate relationships between keywords and research organisations. Table 2 provides a detailed overview of the top 20 countries that have extensively published literature on the effects of nano or microemulsions in wound healing.

Table 2: The top 20 countries contributed to the most literature

Country	Frequency	% (N=349)
India	65	9.46
China	35	4.58
Saudi Arabia	31	8.60
Brazil	31	1.15
United States	28	6.02
Iran	26	2.29
Egypt	21	4.87
Malaysia	17	5.73
Portugal	16	2.87
Australia	10	3.15
Turkey	11	1.15
Spain	13	3.44
Italy	8	2.01
United Kingdom	8	1.43
Pakistan	8	3.72
Greece	5	1.43
New Zealand	3	1.15
Belgium	3	1.72
South Africa	4	3.15
USA	6	1.72
Total	349	100.00

Figure 2: Illustrates the top 20 countries that published the most literature on the effect of nano or nanoemulsions on wound healing generated through VOSviewer analysis from 2011 to 2022, visually representing the global contributions to micro and nanoemulsions in wound healing research. India is the most active publisher, covering 12.09% of total publications, followed closely by Saudi Arabia and China at 10.03% and 10.03%, respectively. The United States and Egypt contributed significantly, with 7.37% and 7.96%, respectively. Larger bubbles indicate higher publication rates, reflecting the extensive global interest in this field

3.3.2 Keywords analysis

Figure 3 shows the relationships among keywords related to wound healing and emulsions. The size of the words indicates how often they occur, while the colour shows when the articles were published. Words like 'wound healing' and 'nanoemulsion' are in light green, indicating their publication dates between 2019 and 2020. 'Wound healing' is the most significant word, meaning it appears the most frequently. The size of the circles and text represent keywords associated with primary terms, such as 'drug delivery system,' 'cell proliferation,' and 'nonhuman.' Key terms like 'wound healing,' 'nanoemulsions,' and 'human' stand out, with 'wound healing' being the most cited keyword, covering 378.70% of all articles. 'Nonhuman' and 'nanoemulsions' follow, constituting 324.52%

Table 3: Top 20 author keywords with the most frequency

Author keywords	Frequency	% (N= 1,713)
Wound healing	185	378.70
Nonhuman	142	324.52
Nanoemulsions	151	309.92
Human	125	296.61
Article	115	253.82
Drug delivery system	99	230.36
Controlled study	94	210.92
Cell Proliferation	36	99.65
Humans	75	185.76
Animals	76	185.46
Animal	70	138.82
Unclassified drug	69	167.72
Nanoparticle	56	145.30
Drug formulation	64	157.21
Chemistry	59	148.98
Animal experiment	68	152.60
Particle size	65	147.58
Animal model	61	141.86
emulsion	47	114.01
microemulsion	57	133.74
Total	1,713	1000.00

and 309.92%, respectively. Table 3 supports these findings, showing that 'drug delivery system' and 'particle size' are among the top 20 keywords. These observations suggest that research focuses on wound healing and nanoemulsions, mainly involving nonhuman experiments in the reviewed studies.

4. Conclusion

The review of PRISMA studies highlights the progress in using nano and microemulsions for wound healing. These formulations have shown significant potential in medical treatments. A bibliometric analysis reveals that India is a leading contributor to nano/microemulsions and wound healing research. Standard terms like 'wound healing' and 'nanoemulsions' appear frequently, reflecting their importance in the studies, which often involve experiments on nonhuman subjects. Institutions such as the Research Institute on Biomaterials are at the forefront of collaborative projects and international partnerships, enhancing the scope and impact of the research. This shared knowledge, analysed through a bibliometric approach, demonstrates how local expertise and global perspectives can foster innovative solutions for wound care. The exploration provides data and insight into the future, where nano and microemulsions could be transformative in advancing wound treatments. Given the potential benefits in pharmaceutical and medical fields, researchers have a strong sense of anticipation. The reviewed papers show the importance of further investigating the unique advantages of these emulsions. The field appears ready for a new phase in medical practice, with micro and nanoemulsions at the forefront of future developments in wound healing.

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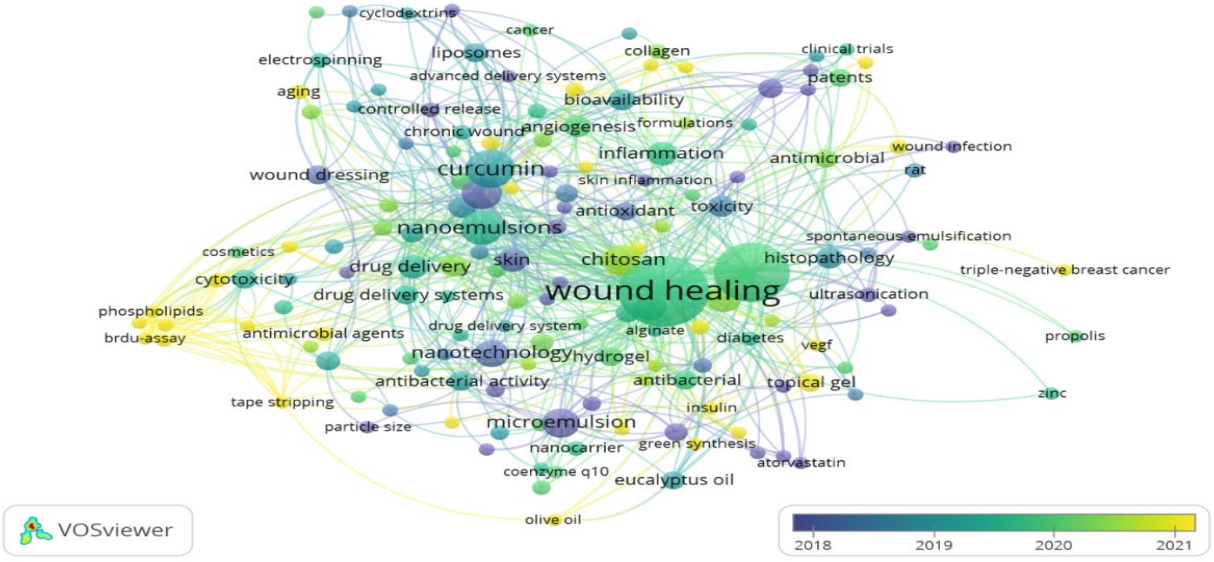

Figure 3: Visually displays the prevalence of 'wound healing' as the dominant keyword (12.09% frequency) alongside related terms like 'nonhuman' and 'nanoemulsions.' Colours and sizes indicate the thematic significance and usage frequency, focusing on wound healing and nanoemulsions in leading publications.

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HALALSPHERE
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The Ministry of Health (MOH) Malaysia policy regarding the use of medications containing non-halal ingredients: an analysis from the *Shari'ah* perspective

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Treatment ruling; Medicines containing non-halal (impermissible) substances; Policy Ministry of Health (MOH) Malaysia; *al-Darurah*

Abstract
This article analyses the policy of the Ministry of Health (MOH) Malaysia against the use of medicines containing non-halal substances according to the *Shari'ah* perspective. This article aims to enlighten pharmaceutical professionals about their responsibilities in the preparation of medications containing non-halal (impermissible) ingredients and the responsibility of the physicians when prescribing drugs that include non-halal components to patients, emphasising that such prescriptions are permissible only in situations of necessity, known as *al-Darurah* (necessity). This article also raises awareness among the public that not all illnesses or diseases can be considered *al-Darurah* except in certain situations permitted by *Shari'ah* (Islamic law). This article also proposes several solutions to the MOH to facilitate the public's usage of medications containing non-halal ingredients based on *rukhsah*. This article uses the qualitative method approach, explicitly incorporating the perspectives of Islamic scholars regarding the necessity of utilising medications containing non-halal ingredients in situations of *al-Darurah*. Furthermore, this article analyses the guidelines implemented by the MOH concerning the usage of drugs containing non-halal substances in Malaysia. This article also seeks to raise awareness among physicians about the vital responsibility they hold in only prescribing medications with non-halal ingredients to patients when it is necessary (*al-Darurah*) and to educate pharmaceutical experts on the significance of disclosing complete details about the non-halal components used.

1. Introduction

It is evident that in both classical and modern Islamic jurisprudence, there are extensive discussions concerning the application of sharia principles in addressing various healthcare issues, particularly within the frameworks of necessity (*al-Darurah*) and need (*al-Hajah*). These include sharia principles related to medications utilising serums derived from carcasses of animals that have not been slaughtered according to Islamic law, as well as medications containing specific drugs or chemicals for medical purposes. Not all ailments are necessarily classified as a state of necessity (*al-Darurah*) and, therefore, do not warrant the use of prohibited substances according to *Shari'ah* law, as their usage is subject to specific circumstances, particularly in assessing the level of necessity for an individual. In examining this issue, the author will first discuss the perspectives of classical scholars regarding the legal aspects of seeking medical treatment using substances prohibited by *Shari'ah* law.

This approach suggests that the use of carcasses and alcohol for medicinal purposes has been a subject of discussion among past researchers. Although there is a general agreement among scholars regarding the need or obligation to consume impermissible foods like carcasses, pork, and improperly slaughtered animals in cases of necessity (*al-Darurah*), such as famine and oppression by individuals, there is a deviation in their views on the permissibility of using medicinal elements derived from carcass, pork, and alcohol.

2. Ruling in getting treatment with medicines that contain non-halal (permissible) substances

According to Ibn Taymiyyah (al-Salami, 2001), seeking medical treatment with medications containing impermissible substances should not be equated to consuming carcasses during famine. The reason for this is that during times of famine, consuming carcasses is highly effective in addressing hunger and saving lives. Meanwhile, the use of impermissible substances in medication still raises questions about its healing abilities. In addition, Sheikh Muhammad Tahir Asyur (al-Salami, 2001) argues that if research has proven the effectiveness of said medication in treating severe ailments, seeking medical treatment with impermissible substances can be equated to the act of consuming carcass during times of famine, which is deemed necessary (*al-Darurah*). In the absence of conclusive evidence proving its effectiveness, it is not valid to compare taking impermissible medications to consuming carcasses during periods of famine.

According to scholarly experts, it is not acceptable to seek medical assistance through the use of prohibited substances, whether ingested, consumed, applied as oil, or involving the utilisation of animal remains and the like (al-Zuhayli, 1991). Based on the words of Prophet Muhammad *(PBUH)*, narrated by al-Bukhari from Ibn Mas'ud: *Indeed, Allah SWT does not make the cure for my people come from impermissible things*. (al-Bukhari, 1987, no.5291; Ibn Hiban, 1993, no.1391; Ibn Hajar al-Asqalani, 1964, no.1792). Similarly, another *hadith* narrated by Muslims states that Prophet Muhammad (*PBUH*) prohibited the production of alcoholic beverages, declared them as drinks and rejected the use of alcohol as a medicinal substance. When Tariq bin Suwayd inquired about the use of alcohol for such purposes, the Prophet Muhammad (*PBUH*) responded, "*Indeed, it is not a remedy; instead, it is (the cause of) illness*." (Muslim, n.d., no.1984)

It can be inferred from these *hadith*s that the use of alcohol for medical treatment is deemed unlawful by the restriction by Prophet Muhammad (*PBUH*), as it is believed to be a transmitter of illness rather than a remedy for any disease.

al-Mubarakfuri (n.d), in explaining this *hadith*, explains that the prohibition of seeking medical treatment with impermissible substances is assumed only when an individual has a choice, as various permissible and impermissible medications are available. It is also believed that the meaning of this *hadith* is directed explicitly towards alcohol and all intoxicating substances, as scholars unanimously agree that alcohol is a cause of illness rather than a remedy. If an individual has no alternative options and a Muslim physician affirms that the impermissible substance is the only viable medication for their ailment, then seeking medical treatment with the impermissible substance at that specific time is deemed permissible.

According to Imam al-Nawawi (n.d) in his work '*al-Majmu'*, the consensus among jurists is that seeking medical treatment with impermissible substances other than alcohol is permissible. However, this permissibility is contingent upon the unavailability of medications derived from permissible substances, as implied by the *hadith* above narrated by al-Bukhari. It is also stipulated that the prescription for such impure medications must come from a professional Muslim physician, even if it is just one. According to Imam al-Bayhaqi, Imam al-Shafi'i does not endorse the consumption of remedies made from snake meat *(al-Tiryaq*) unless in a situation of necessity, similar to the ruling on consuming carcass, based on a *hadith* narrated by 'Amr bin al-'As (may *Allah* be pleased with him). Prophet Muhammad (*PBUH*) stated: "I do not consume *al-Tiryaq* (remedy made from snakes), hang amulets, or produce poetry (verses of the *Qur'an*) from myself." (Abu Dawud, n.d, no.3869).

al-Tiryaq is a type of remedy that contains snake meat. According to Ibn al-'Athir and al-Khattabi (Abadi, 1415H), the consumption of remedies is not fundamentally prohibited, as Prophet Muhammad (*PBUH*) has permitted them for medicinal purposes. However, the prohibition in this *hadith* is precisely due to the remedy containing snake meat and alcohol. Both of these substances are impermissible, and it is impermissible to consume them. If the remedy does not contain these two substances, then the permissibility of its consumption is established (Abadi, 1415H).

Similarly, the ruling on seeking medical treatment with impermissible substances is not obligatory within the Maliki (al-Baji, 1332H) and Hanbali (Ibn Qudamah, 1996) schools of thought. According to Ibn Sahnun (al-Baji, 1332H), it is permissible to treat injuries using the bones of a slaughtered animal. However, using the bones of the carcass, human bones, pig bones, and the bones of animals whose flesh is not permissible to consume is not permissible. If carcass bones are used for healing, according to Imam Malik (al-Baji, 1332H), the person using them should not perform salah (prayers) with those bones. However, Ibn al-Majisyun (al-Baji, 1332H) alleviates this stance by stating that it is permissible to pray with carcass bones used for healing. According to Ibn al-'Arabi (al-Syanqiti, 1995M), seeking medical treatment with carcass is impermissible as long as permissible options can be used as medication. However, some scholars permit seeking medical treatment with the carcass, whether using it solely or mixed with other substances (Khatib al-Riyy, 1995M).

Meanwhile, some scholars among the Shafi'i jurists (al-Kurdiy, 1999M) stipulate that medications containing carcasses or impurities must be mixed with other permissible substances. On the other hand, other Shafi'i scholars do not impose such a condition, basing their stance on textual evidence and its contextual meaning. According to textual evidence, the permissibility of seeking medical treatment with the carcass is derived from a *hadith* that allows the tribe of *al-Uraynah* to drink the urine and milk of camels for medicinal purposes (al-Bukhari, 1987, no.1430; Muslim, n.d., no.1671; Ibn Hibban, 1993, no.1388; al-Tirmidhi, n.d., 1671).

Based on the contextual interpretation of textual evidence, using venomous snake meat as an antioxidant or remedy is deemed effective and beneficial. Therefore, it becomes obligatory to classify it as permissible, as a specification of the general meaning of the *Qur'an*, which states: *"Permitted for you (as food) are all good and pure things."* (verse 4 of Surah al-Ma'idah)

Secondly, Imam Abu Hanifah (Khatib al-Riyy, 1995M) pardoned impurities on clothing up to the size of a *dirham (*a unit of currency) coin due to necessity (*al-Darurah*). Similarly, Imam al-Shafi'i also pardoned small insect bloodstains on clothing due to necessity (*al-Darurah*). Consequently, it is logically plausible to pardon carcass use for medicinal purposes, considering the necessity (*al-Darurah*). Thirdly, *Allah SWT* has permitted the consumption of carcasses for the preservation of human life. Therefore, carcass use in medicine also aims to safeguard human life. However, this permissibility is not absolute, as it is conditioned upon the requirement that the medicine is the only remedy for the disease, and there is no alternative for treatment.

Indeed, even among scholars who permit the use of carcass in medicine, there is a refutation of the argument presented by those who prohibit it based on the above-mentioned *hadith*. They contend that this *hadith* can only be invoked as evidence against matters on which there is a consensus regarding their prohibition. At the same time, the issue of using carcasses for medicinal purposes remains a subject of discussion among scholars regarding its legal status. In contrast, the prohibition of seeking medical treatment with alcohol has gained unanimous agreement among scholars, as previously mentioned (al-Baji, 1332H)

However, according to Khatib al-Riyy (1995), the ruling of seeking medical treatment with alcohol depends on the level of necessity a person is facing. Suppose the necessity reaches the level of *al-Darurah* (extreme necessity). In that case, the ruling

is deemed obligatory, similar to the legal ruling for someone compelled to consume carcasses or other prohibited items in a situation of *al-Darurah* due to the preservation of life. Conversely, if the need for medical treatment does not reach the level of *al-Darurah*, then it is not deemed obligatory.

While the ruling of seeking medical treatment with medications containing drugs or chemicals has been a subject of discussion among classical scholars due to the historical use of such mixtures, particularly in surgical procedures, the fundamental ruling is that the use of drugs is prohibited (al-Kurdi, 1999M). However, it becomes permissible in medical treatment when it constitutes the only available remedy and is based on an urgent need, following the principle of *al-Darurah Tubih al-Mahzurah* (al-Suyuti, 1998; al-Subki, 1991; Ibn Nujaym, 1993; al-Lubnani, n.d.) According to Imam al-Nawawi, it is permissible to employ something that temporarily impairs mental function (anaesthesia) for the amputation of a decaying hand as a resolution to the controversy surrounding seeking medical treatment with alcohol. This viewpoint is also echoed by al-Bakri and al-Syarbini (al-Nawawi, n.d.).

According to al-Mardawi (1376H), impairing mental function (anaesthesia) using *al-Nabj* (a type of drug plant) is considered permissible. The ruling of an individual who loses consciousness due to such anaesthesia is similar to that of a mentally impaired person. However, if someone consumes it without any necessity, the resulting resulting loss of consciousness is similar to that of someone intoxicated. This is because medical treatment is a recognised necessity in Islamic law. For instance, a cancer patient may not be cured except by removing the affected part of the body. The removal of the cancerous part is only feasible through surgery, and surgery is only possible through the administration of anaesthesia to the patient.

Anaesthesia can only be administered through medications containing drugs. Thus, the use of drugs to anaesthetise a patient undergoing surgery is a necessity in that particular situation (Ali Shaykh, 1424H). However, this necessity is conditional, and the anaesthetic dosage from drug-containing substances administered to the patient must be limited to the extent required for a specific treatment period only. For instance, in tooth extraction, the anaesthetic dosage should merely numb the area related to the dental procedure without necessitating the anaesthesia of the patient's entire body. Nevertheless, higher dosages may be administered to patients undergoing prolonged surgeries such as abdominal or cardiac procedures (al-Syanqiti, 2004M). This is because the necessity of using substances containing drugs or toxins depends upon the requirement. Thus, the legitimacy of their use is confined solely to the necessity of anaesthetising the patient for the duration required for the treatment.

There are several rights of the patient and responsibilities of the anaesthesiologist during the period when the patient is under the influence of anaesthesia. Firstly, the anaesthesia specialist must determine the dosage of anaesthetic required for a patient in a particular surgery, considering both the duration of the procedure and the patient's tolerance to the anaesthetic substance. Suppose a surgical procedure only necessitates local anaesthesia. In that case, it is prohibited for the anaesthesiologist to administer anaesthesia to the entire body of the patient unless there is a compelling need to do so. This is because the anaesthetic substance contains toxins that could be fatal if the dosage exceeds the limit tolerable by the patient's immune system.

In conclusion, within the healthcare service, various entities are involved in situations of necessity, including the patient, healthcare providers (physicians and nurses), medication or treatment methods, and treatment facilities. The patient is the primary subject in this healthcare service because the healthcare system, including nurses, medications, treatment methods, and facilities, cannot function without the patient. The patient is the central focus of healthcare services and is in a state of illness that places them in a condition of difficulty (*al-Masyaqqah*) (al-Suyuti, 1998; al-Subki, 1991; Ibn Nujaym, 1993) in either the state of necessity (*al-Darurah*) or need (*al-Hajah*), it is evident that numerous matters fall under the category of permissibility (*Rukhsah*) in dealing with a patient based on their illness and the treatment requirements.

The situation of necessity (*al-Darurah*) or need (*al-Hajah*) for patients inevitably brings along several other reflections, placing them in a state of necessity or need. Critical situations, such as life and death, the possibility of disability, the potential spread of epidemics caused by viruses and bacteria, or similar circumstances that threaten public safety, are recognised in Islamic jurisprudence as critical situations falling under the categories of necessity or need. Consequently, not only do patients receive the legal concession (*Rukhsah*) (Dr Abu Bakr Isma'il, 1997), but physicians, nurses, medications, and treatment methods also share in receiving this legal concession based on the extent of the patient's needs in a given case.

Treatment for any illness that poses a threat to life is considered treatment at the level of necessity (al-Darurah) and may be applied to patients even if it involves the use of medications containing chemicals, drugs, or substances derived from carcasses or non-permissible animals, in quantities required, and in the absence of alternatives. Similarly, treatments with associated risks may be applied to patients in a state of necessity (*al-Darurah*) due to their illness (Zaydan, 2003; Ulwan, 2000).

3. The MOH Malaysia policy regarding the use of medications containing non-halal ingredients

Examining the laws and policies of the MOH Malaysia through acts, policies, circulars, and guidelines specifically related to the use of medications containing toxins on patients, several acts are pertinent to the drugs employed by MOH. These include the Pharmacists Registration Act 1951 (Laws of Malaysia, Act 371); Dangerous Drugs Act 1952 (Laws of Malaysia, Act 234); Poisons Act 1952 revised 1989 (Laws of Malaysia, Act 366) and Medicines (Advertisement and Sale) Act 1956 (Laws of Malaysia, Act 290).

The Dangerous Drugs Act 1952 aims to regulate and establish rules regarding the import, export, manufacture, sale, and use of opium and other dangerous drugs. This Act provides further provisions for better control over the import, export, manufacturing, sale, and use of opium and certain dangerous drugs. Additionally, it makes specific provisions regarding the jurisdiction of the courts over offences falling under its purview and the trial proceedings of the court.

Meanwhile, the Poisons Act 1952 aims to regulate the import, possession, manufacture, sale, and use of poisons. 'Poisons' refer to substances named and listed in the 'Poison List', including any mixture, preparation, solution, or substance containing these materials or any preparations or substances contained in Schedule Two of this Act. The Medicines (Advertisement and Sale) Act 1956, on the other hand, aims to

regulate and prohibit advertisements referring to any goods deemed capable of influencing their use as medicines for treating specific severe conditions. All advertisements for medicines must obtain approval from the MOH.

Examining the enforcement of laws regarding medications containing toxins or drugs, the author finds that it is heavily emphasised within the MOH. It can be said that all acts utilised within the MOH concerning the regulation of medicines revolve around the regulation of the preparation, manufacture, importation, sale, and advertisement of medicines containing toxins or drugs. The legal implications contained in the Dangerous Drugs Act 1952 (Laws of Malaysia, Act 234), Dangerous Drugs Sale Act 1952 (Laws of Malaysia, Act 368), and Poisons Act 1956 (Laws of Malaysia, Act 366) are clear concerning those who violate the regulations within these Act.

Within the MOH, determining the quality of medications, law enforcement, and monitoring are carried out by the Pharmacy Services Division of the MOH (www.pharmacy.gov.my). The Pharmacy Services Division (PSD) is one of the divisions under the Research & Technical Support Program in the MOHMalaysia. The primary responsibility of the PSD is to ensure that pharmaceutical materials and healthcare provisions provided to the public are of high quality, safe, and effective. They are prepared with full responsibility to produce positive effects and improve the quality of life. The PSD comprises three main sections: the National Pharmaceutical Control Bureau, the Pharmacy Enforcement and Licensing Branch, and the Pharmacy Practice Management.

National Pharmaceutical Regulatory Agency (NPRA) directly contributes to public health through the determination of the quality of medications, involving the assessment and registration of drugs before marketing; control over the import, manufacturing, wholesale, and sale of drugs through a licensing system; and continuous monitoring of the quality of registered drugs in the market through a quality surveillance program. Meanwhile, the Pharmacy Enforcement and Licensing Branch ensures that the enforced acts and regulations carry out the manufacturing, importation, sale, distribution, management, and use of pharmaceuticals, cosmetics, and healthcare products (www.pharmacy.gov.my).

The Pharmacy Practice Management is accountable as the Secretary to the Drug List Review Panel of the MOH. It formulates policies for pharmacy practices related to service requirements, skill refinement, human resource development, administrative functions, and allocation distribution. This division also provides technical advisory services in drug procurement, medical product output, supply, and distribution (www.pharmacy.gov.my).

In addition to the aforementioned acts, the MOH has issued policies that illustrate its firm stance on the use of medications containing toxins or drugs, namely the Malaysian National Medicines Policy (MNMP). This policy outlines one of its objectives, which is to ensure that medicines marketed for patient care are safe, effective, of high quality, and meet global health requirements (Malaysian National Medicines Policy, 2009).

To what extent is the law enforced in the acts utilised by the MOH, and what is the MOH's stance through policies and guidelines regarding the halal *(*permissible*)* status of medicines? Halal medications must adhere to characteristics such as not consisting of or containing substances from animals that are prohibited by Islamic law for use or consumption, or not slaughtered according to Islamic law; not containing substances deemed impure according to Islamic law; not prepared, processed, manufactured, or stored using any tools that are not free from impure substances according to Islamic law; not coming into contact or proximity with any substances that do not meet the requirements above or any substances deemed impure according to Islamic law, and intentionally using it should not result in harmful effects (www.islam.gov.my/e-rujukan/ubat.html).

However, in certain circumstances where there is no permissible substance available for treating a particular illness, Muslims are allowed to use impermissible substances for medicinal purposes. Exceptions in using impermissible substances as medicine should meet conditions such as the unavailability or difficulty obtaining permissible substances to treat the related illness. The use of such substances should be under the guidance and advice of a physician, and the consumption of medicine from impermissible substances should be limited to what is necessary (www.islam.gov.my/e-rujukan/ubat.html).

This implies that not all illnesses necessitate the use of medications derived from non-halal substances, especially if there are alternative halal medications available as a cure. This means that medications containing toxins or drugs also fall into the category of prohibited medications if there are alternative halal drugs. The permissibility of a medication is evaluated based on three aspects: the source of the medication, the source of excipients, and the cleanliness aspect in the preparation and handling of the medication.

4. Analysis

In Islam, something clean does not necessarily mean it is pure. Something impure is considered *najis* (pollutant). Therefore, the main question here is the extent to which the ruling of MOH medications can be determined based on the purity of the drug source and excipients and how it can be identified. The author found that none of the acts, policies, or guidelines used by the MOH regarding drug regulations address these issues. For the MOH, the safety of drug use is crucial, leading to strict and transparent laws and policies on the matter. Meanwhile, for Muslim patients, the use of halal medications in non-emergency situations is equally important as the safety concern.

The sources of drugs can be categorised into several groups: human, animal, plant, soil, and water. These sources are often utilised to produce substances that can be used as medicine. However, with today's modern technology, most drugs use synthetic materials. Essentially, for a drug to be classified as halal, not only must the sources used as drug ingredients be halal, but the ingredients themselves must also be pure from impurities according to Islamic law and be used for legitimate medical purposes. Excipients are substances that process a particular form of medication, such as starch, capsule shells, solvents, sugar, colourants, flavourings, preservatives, etc. Excipient materials are considered halal if they do not contain impure, impermissible, toxic, and harmful substances. There is no exemption from the prohibition of using excipient materials derived from impermissible substances.

In addition to being safe, effective, and high-quality, halal is a condition that determines whether a particular medication can be applied to a patient. Only in situations of *al-Darurah*

(necessity) are medications from non-halal sources allowed to be administered to patients, such as when there is no alternative, it is challenging to obtain what is halal or threatens the patient's life. Nevertheless, the 8th Muzakarah of the National Fatwa Committee of the Malaysian Islamic Religious Affairs Council, held on September 24 – 25, 1984, decided that the use of gelatine in medications at that time was permissible due to *al-Darurah* (*Muzakarah Jawatankuasa Fatwa Majlis Kebangsaan Bagi Hal Ehwal Ugama Islam Malaysia, 2015*). However, they stipulated that if there were *halal* substances available that could prevent the medication from deteriorating rapidly, then the use of gelatine in medications would no longer be obligatory (www.e-fatwa.gov.my/fatwa-kebangsaan).

Thus, labelling medications into several categories will facilitate the physicians' selection of medications for prescription to patients. The enforcement of the '*halal*' labelling will enable physicians to prescribe halal medications to patients when there are alternative medications (both halal and non-halal). In situations where there are no halal medications available, physicians may prescribe non-halal medications only as necessary for the patient. Labels such as 'contains non-halal ingredients,' similar to the labelling of 'controlled drugs,' may be used as notifications to patients regarding the conditions of the medications they are using.

Meanwhile, medications containing non-halal excipient sources should also be labelled. This is because they cannot be applied to Muslim patients due to the prohibition's absence of legal exceptions. Excipient sources are not medications; they are additional substances used to process a particular form or type of medication. Medications can still be applied to patients without them. In this regard, the MOH should be firm through its acts, policies, or guidelines regarding the prohibition of using excipient sources from non-halal materials since alternative excipient sources from halal materials currently exist. Excipient sources from non-halal materials should be labelled 'contains non-halal excipient sources' so physicians can avoid applying or prescribing them to patients.

In Malaysia, Jabatan Kemajuan Islam Malaysia (JAKIM) issued several fatwas regarding the ruling against the use of certain medicines and vaccines. The Fatwa Committee of the National Council for Islamic Religious Affairs Malaysia's 6th Meeting, held on October 10, 1983, discussed the Injection of Highly Purified Insulin from Pigs (*Muzakarah Jawatankuasa Fatwa Majlis Kebangsaan Bagi Hal Ehwal Ugama Islam Malaysia, 2015*). The committee ruled that injecting insulin derived from impure (pig) sources for the treatment of diabetic patients is permissible due to necessity (*al-Darurah*). The same ruling applies to those administering the injection.

The 81st Muzakarah of the National Fatwa Committee of the Malaysian Islamic Religious Affairs Council held on March 31, 2008, also discussed the ruling of using vaccines that contain pig-derived substances in their production process (*Muzakarah Jawatankuasa Fatwa Majlis Kebangsaan Bagi Hal Ehwal Ugama Islam Malaysia, 2015*). The committee ruled that the use of the BioThrax and RotaTeg vaccines is impermissible because the current situation is not considered an emergency (non-*al-Darurah*), there are alternative substances or medicines available other than the use of pig-derived elements in the production of both vaccines, and there is no strong supporting data to prove that the citizens of this country require both vaccines.

Similarly, the 87th Muzakarah of the National Fatwa Committee of the Malaysian Islamic Religious Affairs Council, held from 23rd to 25th of June in 2009, discussed the ruling on the use of *Clexane* and *Fraxiparine* as medications (*Muzakarah Jawatankuasa Fatwa Majlis Kebangsaan Bagi Hal Ehwal Ugama Islam Malaysia, 2015*). The committee concluded that Islam prohibits the use of medications derived from impermissible sources to treat any illness, except in situations where no medications from permissible sources are available, and to avoid harm, only the necessary amount should be used until medications from permissible sources are found. Therefore, regarding the use of *Clexane* and *Fraxiparine* medications, which are considered essential for patients to prevent immediate blood clot formation when they are in a chronic state, the committee ruled that the use of both types of medications is prohibited because they are produced from sources prohibited by Islam. This is especially considering that there is now an alternative medication, *Arixtra*, produced from permissible sources, with similar functions and effectiveness as *Clexane* and *Fraxiparine*.

The time has come for the MOH to improve its acts, policies, and guidelines related to drug regulations through several enhancements, as discussed by the author above. For a long time, physicians in Malaysia, including Muslim physicians, have been prescribing non-halal medications to Muslim patients, even when there are halal alternatives available or when patients are not in situations of necessity to use these non-halal medications. Furthermore, the use of medications with non-halal excipients, which has never been exempted from the prohibition of its use in Islamic law because it does not fall under the category of necessity, is of concern. The labelling and enforcement of the sources of drugs, excipients, and purity in drug preparation should be established as laws and policies by the MOH.

Non-halal medications consist of two components: containing toxins (drugs) and non-halal substances (vaccines from animals that have not been slaughtered or are not halal to consume). These medications are permitted when there is no alternative to halal medications in two situations: *al-Darurah* or *al-Hajah*. When there are multiple medication options for a particular illness, and these medications are composed of various substances, including some made from non-halal ingredients, physicians should prescribe medications made from halal ingredients if they can be ensured or distinguished between halal and haram medications. However, suppose a physician cannot ascertain the content of these medications based on this principle. In that case, the physician must determine the content of the medications to identify those that are halal or, at the very least, those with minimal non-halal ingredients from the list of medications provided by the MOH pharmacy.

According to the authors' view, in today's situation where the content of substances in medications is listed and attached to the medication packaging, physicians do not need to engage in *ijtihad* (independent reasoning) to determine the permissibility of the content of these medications because it is already documented. Physicians are required to exercise *ijtihad* in determining the permissibility of medications if they are mixed with non-permissible medications in situations where the content of the medication is unknown. When physicians are aware of the content of medications and can distinguish between halal and *haram* medications, the physician must prescribe medications whose permissibility is assured.

The MOH has blatant acts and policies regarding medications containing toxins or drugs. The list of drug or toxin names is explicitly and extensively outlined in the Poison Act. Pharmacists are knowledgeable about the content of a vaccine in terms of its source, whether from animals or synthetic origins, the type of animal serving as the vaccine source, and whether it is permissible to consume. However, they may not be aware of whether the animal has been slaughtered in a permissible manner or if it is considered permissible to consume. Therefore, in this situation, physicians need to make an effort to gather information about the content and sources of these medications to ensure that the medication with the least ruling complication is chosen among the various medication options available for the patient.

Suppose a particular disease has alternative medications, all of which contain drugs. In that case, the physician should choose medications with the lowest drug content or the mildest side effects resulting from the intake of drugs. In the author's opinion, suppose there are multiple options for a particular disease, and they are mixed with medications containing non-halal substances. In that case, the physician should choose medications containing drugs because they are made from plants, and their quantity has been ensured safe.

This is because drugs are prohibited due to their impact on cognitive functions if taken excessively. Meanwhile, medications containing substances from prohibited animals or from the carcasses of animals that are halal to eat are prohibited because of the animal or carcass itself, not its effects. If the medication options are mixed between halal and *haram*, the physician must determine which to give to the patient.

In the current pharmaceutical industry, all drug manufacturers must list the contents and quantities of the ingredients in a drug. The concept of cleanliness, which involves trying to seek or identify what is halal, has become more accessible due to the ease of checking the list of ingredients provided by pharmaceutical companies. Moreover, if the Fatwa Committee has issued a fatwa regarding the use of a particular drug, it further facilitates the determination of its permissibility. For example, the Muzakarah of the Fatwa Committee of the National Council for Islamic Religious Affairs Malaysia, Session 53, held on 27th November 2002, discussed the injection of Meningococcal Meningitis Vaccine by Muslims. The Muzakarah ruled that using the *Meningococcal Meningitis Mencevax* vaccine derived from bovine sources is permissible. Meanwhile, the *Meningococcal Meningitis Monumune* vaccine contains elements derived from pigs and is considered impermissible.

5. Conclusion

In conclusion, the MOH has explicit policies regarding medicines containing drugs. However, the policies or guidelines for physicians regarding the use of halal drugs or the selection of various drugs for a particular disease that may include toxic and non-toxic halal and *haram* substances are not yet fully enforced. As a medical institution that frequently employs the principle of *al-Darurah* in its services, clear guidelines regarding the obligation to prescribe halal drugs and those with fewer side effects (in cases where there are various drug options for a particular disease, including a mixture of halal and *haram* substances) are essential and should not be underestimated. It is an obligation for healthcare practitioners and should be implemented in line with the legal provisions of *Shari'ah*.

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Exploring environmental, social and governance (ESG) in the halal industry in Brunei

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Abstract

This article aims to explore the extent, approaches and challenges of Environmental, Social and Governance (ESG) principles' incorporation into the halal industry with Brunei Darussalam as the case study. This is based on multiple factors, especially economic diversification. A qualitative approach with a case study analysis was employed, utilising solely library data on ESG and observational insights on Brunei. As a result, this study finds that it is possible to incorporate ESG within Brunei's halal industry. It comes with challenges such as low purchasing power due to the small population, unemployment issues, and perceptions of ESG centred around developed countries. Coupled with limited data, the solutions to the challenges are unknown. Thus, collaborative efforts from all stakeholders are required. Addressing these challenges could enable Brunei to align its halal industry with ESG principles for realising Wawasan Brunei 2035.

1. Introduction

The current halal scene has been evolving in literature, focusing on 'sustainability'. Notably, environmental sustainability follows the urgency to fulfil the United Nation's seventeen sustainable development goals (17 SDGs). These goals aim to address global challenges such as poverty, hunger, equality and fostering partnership, with an achievement target by 2030. However, as SDGs are aimed at countries as a whole, Environmental, Social and Governance (ESG) have become prominent in the discussion. It becomes a significant element for companies as it provides a mechanism based on a criterion (Hashim *et al.*, 2023) for environmental sustainability while also fulfilling the societal and governance impacts (De Hoyos & Dib, 2022). Similarly to SDGs, ESG was also popularised based on global concerns (Li *et al.*, 2021), such as global climate change, which led to prioritising sustainable efforts. However, ESG was seen prominently within finance in responsible investment (Li *et al.*, 2021). Mainly due to the rising awareness that sole financial profit would be useless long-term in the face of social inequalities (De Hoyos Guevara & Dib, 2022) and depleted natural resources.

As ESG evolves, it has encountered an expansion outside of its norms. It is recognised as a vital component of the potential of the halal industry (Hashim *et al.*, 2023). With the industry's growing demands from rising Muslim populations (Sulaiman *et al.*, 2023) with a trillion-level revenue estimate, aligning it with the current worldwide goals is logical. This includes parallel alignment with the Net Zero by 2050 agenda (Ramli *et al.*, 2022) and achieving the SDGs that ESG can offer. It also offers prospective benefits like company image and reputation betterment (Prabawati & Rahmawati, 2022; Li *et al.*, 2021).

Coupled with this, ESG principles also align with Islamic values. This can be an added benefit for the halal industry as its emergence stems from the demands of Islam as stated in surah al-Baqarah, verse 168:

> "O humanity! Eat from what is lawful and good on the earth, and do not follow Satan's footsteps. He is truly your sworn enemy."

Based on the verse above, the emphasis in the original Arabic text on consuming the 'lawful' and 'good on earth' utilises 'halalan tayyib' and has shaped the halal industry.

Meanwhile, for clarity on ESG and its Islamic value alignment, Hashim *et al.* (2023) have provided examples that are the core of ESG—for example, conserving the environment, promoting justice and respecting one another. At the same time, these values hold the same virtues taught by the Prophet Peace be Upon Him (*PBUH*). Thus, it signifies its importance to be ingrained in the halal industry for its embodiment of religious values. These values also extend to humans and non-humans, i.e., animals, the planet, and nature. Especially for Brunei Darussalam, incorporating ESG within the halal industry holds significant potential. To showcase this rationale, a few examples can be put forth:

Firstly, regarding the mandatory halal application under the Halal Certificate and Halal Label (Amendment) Order, 2017,

for food establishments in Brunei. This demonstrates the entrenched role of halal principles within the country and the strength of its foundation.

Brunei's official religion is Islam (Ministry of Foreign Affairs Brunei, 2018). Thus, it is logical to embed Islamic-based ESG principles to strengthen halal integrity further and uphold religious values within the country's halal industry.

Lastly, answering the urgent call for economic diversification needs within Brunei. The country's economy is stagnant and weak post-COVID-19 recovery (Koh, 2024). Koh (2024) also states how Brunei needs to step up to recognise and tap into 'green growth opportunities' by utilising the natural advantages they are equipped with. Therefore, incorporating ESG principles into the halal industry can assist Brunei in addressing environmental, social and governance concerns. Then, in return, advancing both economic and sustainability goals. Simultaneously, it can help Brunei launch the industry towards the global halal hub vision for Wawasan Brunei 2035 realisation (Sulaiman *et al.*, 2022).

Based on this rationale, this study aims to investigate ESG in general and evaluate its adoption in Brunei, particularly within the halal industry. For this, the discussion of this paper will be divided into five (5) parts:

1) An exploration of current ESG practices, principles and frameworks.
2) A review of the adoption of ESG principles in Brunei Darussalam.
3) Examining how ESG principles are incorporated into the halal industry.
4) An analysis of the application of ESG within the halal industry in Brunei.
5) Identifying the challenges associated with implementing ESG principles in the industry.

This approach will comprehensively understand ESG's role in enhancing Brunei's halal industry and its broader economic and sustainability objectives.

2. Materials and methods

This study has adopted a qualitative research method with Brunei as its case study in exploring ESG for the halal industry. Given ESG's initial stages of awareness and breakout from its norms of association, this study believes that library-based research is appropriate for the study's nature. Furthermore, obtaining primary data through interviews and surveys would be difficult following minimal established practices in the country. Considering this would provide resource and time constraints.

Additionally, this study employs a case study analysis to provide a comprehensive view of the country's situation and the necessary background on ESG and halal in Brunei. This approach aligns with the study's objective as solely foundational and general research on the matter. Hence, this study primarily utilises these three (3) types of articles:

1) ESG-based data that do not conform to the halal industry,
2) Current laws, directives, trends, and reports on Brunei Darussalam related to ESG,
3) The environment of the halal industry in Brunei Darussalam.

This paper also incorporates the authors' observations following the considerations of ESG through analysing social media posts and relevant mediums. Although they do not explicitly mention ESG, its principles are implicitly indicated through keywords and messages.With the case study analysis and the multiple data sources, the study can provide an in-depth contextual view of ESG and Brunei's halal industry.

3. Result and discussion

3.1 The present ESG practices, its principles and framework

ESG practices have been part of conversations for many years. Due to the attractive offers and benefits for companies, numerous businesses have adopted ESG frameworks. Brunei is no exception, which will be explored further in this paper. Unlike solely 'going green' or sustainability, ESG offers a tri-dimensional approach that integrates environmental, social and governance aspects. Tarmuji *et al.* (2016) explain the connection of three aspects: environmental actions within the company will impact the social aspect. Thus, upholding environmental and societal responsibility will require sound governance principles.

Moreover, various scholars within academia have defined the principles of ESG differently. However, it is agreed that it is a set of guidelines (Shapsugova, 2023; Prabawati & Rahmawati, 2022) that provides a directive towards sustainable efforts and ethical impacts for an organisation. To better comprehend the ESG principles, Table 1 by Li *et al.* (2021) provides a clear framework on the matter.

Currently, ESG performance is monitored through a reporting system called an 'ESG score'. These scores are tracked within the company using targets and benchmarks provided (Krantz & Jonker, 2024). However, ESG is much more evident in countries like the United States or Europe, where their markets have reached billions or trillions of dollars (UNDP, 2024). Meanwhile, ESG still lags in Asia despite the market value of 3 trillion USD. For scale, the United Nations Development Programme (UNDP) states that Asia only takes up 3% of the previously mentioned value (2024). As for ASEAN-specific countries, Malaysia is said to be a leading country with disclosed sustainability rates of 64.5%, according to Loh *et al.* (2016), as cited by Mohamad *et al.* (2021). Singapore, Thailand, the Philippines and Indonesia follow Malaysia in ESG implementation. Although Brunei Darussalam is also an ASEAN country member, Prabawati and Rahmawati (2022) mention that ESG awareness is still in the initial stages. Thus, this leads to a lack of information on ESG within the country. Despite this, there have been advancements in ensuring the environment in Brunei is heading towards ESG principles.

3.2 Adoption of ESG principles in Brunei Darussalam

Sustainability has become a rising topic in Brunei Darussalam, especially in fulfilling the SDGs. Under its Second National Voluntary National Review (VNR), Brunei Darussalam reported its progress in sustainable development during the 2023 High-Level Political Forum on Sustainable Development. This report shows Brunei Darussalam's continued commitment to the 2030 agenda regarding this area.

Table 1: ESG framework (international frameworks)

Dimension	Factors	Definition
Environmental (E)	• GHG emissions • Energy consumption and efficiency • Air pollutants • Water usage and recycling • waste production and management (water, solid, hazardous) • impact and dependence on biodiversity • impact and dependence on ecosystems • innovation in environmentally friendly products and services	Environmental matters that may positively or negatively impact the financial performance or solvency of an entity, sovereign, or individual.
Social (S)	• workforce freedom of association • child labour • forced and compulsory labour • workplace health and safety • customer health and safety • discrimination, diversity and equal opportunity • poverty and community impact • supply chain management • training and education • customer privacy • community impacts	Social matters that may positively or negatively impact the financial performance or solvency of an entity, sovereign or individual.
Governance (G)	• codes of conduct and business principles • accountability • transparency and disclosure • executive pay • board diversity and structure • bribery and corruption • stakeholder engagement • shareholder rights	Governance matters that may positively or negatively impact the financial performance or solvency of an entity, sovereign or individual.

Source: Li *et al.*, (2021). ESG: Research progress and future prospects.

Thus, Brunei Darussalam is fulfilling its responsibility to end poverty, protect the planet, and ensure global communities enjoy peace and prosperity by 2030.

This effort can be observed by aligning all seventeen SDGs with Brunei's agenda: Wawasan Brunei 2035 (See Figure 1). It has been noted that creating a firm path towards sustainable development requires cooperation from all sides. Therefore, efforts must be made holistically to ensure impact while meeting the population's needs, including the future generation.

Although ESG has not been mentioned explicitly, its existence is vital in achieving the second goal in Wawasan Brunei 2035: 'High Quality of Life' (See Table 2).

Based on Table 2, there is evidence that all aspects of ESG are mentioned within the goals. It has included dimensions such as the importance of having good governance, social harmony, and environmental sustainability. However, ESG is more common within the finance sector for its actual adoption in Brunei. For example, Bank Islam Brunei Darussalam's (BIBD) Arabesque Q3.17 SICAV - Global ESG Momentum Flexible.

Allocation Fund (BIBD, 2023). This fund was launched in 2022, and its ESG practices received recognition from Global Outlook Magazine. Other examples include Baiduri Bank and its ESG initiatives (Baiduri Bank, 2024), which include waste reduction strategies.

Figure 1: The alignment of Wawasan Brunei 2035 and the sustainable development goals (SDG).
Source: Prime Minister's Office, (2023). Brunei Darussalam Voluntary National Review Report 2023.

Meanwhile, other sectors, such as oil and gas, like the Brunei Shell Petroleum (BSP), have also proudly advocated for environmental conservation while showing commitment to social and governance aspects, such as BSP's Social Investment and Shell Livewire. Total Energies Brunei has alsoorganised the 'Sustainable ESG Start Program' as a four-day programme with the United Nations Global Compact Network Malaysia and Brunei (UNGCMYB). This programme targeted small and medium enterprises (SMEs) to help them create a sustainable action plan. As for the micro-enterprises, the following

Table 2: Wawasan Brunei 2035 'High Quality of Life' National Outcomes and Key Areas

Wawasan Brunei (2035).	National Outcomes	Key Areas
High Quality of Life	High standard of living	• healthy nation • access to high-quality public utilities and infrastructure • high home ownership • high social mobility • excellence in service delivery
	Upholding sovereignty	• one of the safest countries in the world
	Sustainable environment	• a clean and green environment
	A resilient and cohesive society	• inclusive and sustainable social security • population with core values • social harmony through community
	World-class health and safety	• compliance with occupational health and safety legislation

Source: Wawasan 2035, (2019). High quality of life.

workshop was created months after the initial ESG workshop with SMEs by the Prime Minister's Office (PMO) (Special National Coordinating Committee on Sustainable Development Goals, 2024) to provide them with basic ESG knowledge. Specifically, the Special *et al.* Committee on Sustainable Development Goals (SDGs), with Total Energies and UNGCMYB.

Regarding other government efforts, although it is not explicitly mentioned as ESG and is related more to the 'E' aspect, it includes the 'Protokol Hijau' and a directive that calls for mandatory reporting of greenhouse gases (GHG). 'Protokol Hijau' is a guideline launched on 30th January 2021 by the Brunei Darussalam National Council on Climate Change (BDNCCC) to be utilised within public service premises. Meanwhile, the GHG reporting directive was said to be effective by 19th April 2023, which requires all facilities that emit or remove GHG to submit their GHG report (Brunei *et al.*, 2023). However, a grace period was mentioned for the first two (2) years (2023 and 2024) that allows submission past the formal quarterly deadlines. This directive also contributes to the 'G' aspect, as it is also an initiative by the government to provide enhanced transparency and accountability (Prime Minister's Office, 2023).

As for NGOs, Brunei consists of passionate youths who have helped create awareness and avenues for other youths to join in helping the community. These include Green Brunei, Young Professionals Network (YPN) Brunei and Brunei Youth Council (BYC). These NGOs have consistently advocated for the 'E' and 'S' aspects in Brunei, primarily through tree planting initiatives and charity drives, including advocating for SDGs through youth dialogues and relevant avenues.

Furthermore, statistics on Brunei's governance show it ranks in the high percentile. Particularly for political stability, government effectiveness, regulatory quality and its control of corruption are within the 80-90 percentile rank in 2022 (The World Bank, 2024). Brunei is also ranked the highest, along with Singapore, in terms of ASEAN in controlling corruption (Rosli & Kamaluddin, 2021). This shows Brunei's strength and its advantages in ESG adoption.

3.3 The extent of ESG in Brunei's halal industry

Other countries acknowledge the halal industry in Brunei to be 'stringent' (Haji Ibrahim, 2020) based on its standards and laws. Unlike others, it is also mandatory, as mentioned in this paper. Due to this law, the Muslims in Brunei and tourists alike are reaping the benefits as most restaurants within the country are halal-certified and entirely safe for Muslim consumption. However, the industry is only centred around halal, safety and cleanliness. As for other aspects, such as ESG and sustainability, there is yet to be an emphasis on them aside from within academic literature. Albeit so, there has been a slight movement in the industry towards the direction of sustainability, as seen during the *Seminar Antarabangsa Produk dan Perkhidmatan Halalan Thayyiban ke-6 (SAPPHAT)* 2023 (Mohamad, 2023). Here, BIBD has extended its support as the primary sponsor in its commitment to creating a sustainable halal industry. However, other than this event, the industry still lags on the ESG or sustainable bandwagon despite its significance and the multiple calls within the academia for its implementation.

Regardless, based on the authors' observations, some companies practice ESG principles, particularly in the halal food industry. Hence, a breakdown of each element of ESG is provided below about the halal industry based on the observations mentioned:

1) The halal industry and the 'environmental' element.

The environmental element refers to the approach businesses implement to ensure responsible and sustainable practices for environmental preservation. In Brunei, several companies have adopted these practices. For instance, in Radisson Hotel Brunei Darussalam's food establishments, 'Tasek Brasserie' and 'Riwaz Restaurant', this hotel uses the slogan "Take all you can eat, eat all you can take" to remind consumers not to waste food. This practice is an example of environmental responsibility by supporting Brunei's efforts to reduce waste sent to landfills.

On that note, imposing additional fees to customers for leftover food is another approach a few small businesses have taken in the country. This initiative discourages food waste and is primarily prevalent in buffet-style restaurants. This method encourages customers to consume their food responsibly to

avoid additional fees.

Furthermore, Dil's Café has announced a partnership with GROW (generate reusable organic waste), an initiative led by several officers under the Executive Development Program Middle Management Officers, 35th Cohort (EDPMMO-35). This initiative focuses on food waste management with guidelines for food service providers through monitoring and auditing of food waste. These actions are highly commendable and highlight their commitment to environmental sustainability.

2) The halal industry and the 'social' element.

The social element refers to the impact of businesses on society, the community and their employees, as seen in Table 1 previously. For this element, a few examples can be seen in the country:

Within Radisson Hotel, employees are recognised for their contributions to the company. This recognition is vital to promoting growth and mutual respect among employees and maintaining a positive work environment. Little Audrey's Café also acknowledges the essential role of its staff in creating an outstanding experience through great hospitality and customer service. This focus is a key aspect of the social element of ESG to enhance employee satisfaction and retention.

Other notable companies include The Coffee Bean & Tea Leaf Brunei for their 'The Caring Cup' program with the "Coffee for a Cause" campaign. As part of their community engagement responsibility, the campaign raises funds and awareness for the Welfare of Persons with Different Ability (MKOKU).

3) The halal industry and the 'governance' element.

The governance aspect refers to transparency and accountability within the company. For the halal industry to ensure its integrity, transparency is at its core and warranted by all halal-certified establishments before a certification can be issued. However, good governance also requires transparency between employees to ensure fair rights. The Coffee Bean & Tea Leaf reports their usage of corporate social responsibility (CSR); however, not many details have been uncovered.

3.4 Applying ESG in the halal industry in Brunei Darussalam

Brunei's business landscape is mainly taken over by micro, small and medium enterprises (MSMEs) by 97% in 2022 (Department of Economic Planning and Statistics Brunei, 2023). Hence, the APEC Business Advisory Council (ABAC) introduced the MSME ESG and Sustainability Framework, which provides MSMEs with initiatives to implement ESG within their companies. This initiative involves following through an eight-step approach:

1) Performing an ESG scan,
2) Identifying and implementing key achievable ESG initiatives,
3) Setting goals and implementing a process to track progress,
4) Implementing an automated, simple reporting approach,
5) Implementing a review mechanism and making improvements,
6) Ensuring the value chain is part of the ESG approach and MSME's ecosystem is measured,
7) Adopt a cost-effective approach,
8) Seeking local support (Curry & Abdul Haadii, 2023)

Although its implementation is challenging, there are avenues to help companies transition to an ESG principle-based company. The United Nations Global Compact Malaysia and Brunei (UNGCMYB) offers resources and tools to ease the transition in Brunei. This also includes an 'ESG START Programme' (UNGCMYB, 2023). Through this programme, companies can act on the ABAC approach, benefiting from the guidance of experts and peers through online sessions provided by the UNGC Academy. This makes it easier for companies to gain the necessary knowledge for the implementation.

Furthermore, this approach is not specific to any industry but is open to all MSMEs. Therefore, the halal players within MSMEs may also apply these approaches within their companies.

However, the government also has an essential role as one of the key stakeholders in the halal industry. Creating a conducive environment for halal companies through engagement and encouragement is vital to facilitate the transition towards ESG incorporation—for instance, workshops, as previously made to provide the necessary knowledge. However, to fully engage companies striving for ESG incorporation, the government should utilise reward-based systems such as monetary gains or waivers upon application. Similar approaches have been made in the country, such as electric vehicles (EVs). A 2-year road tax waiver (Noor, 2022) was offered to popularise them. With incentives like these, the probability of companies incorporating ESG would increase, following economic and financial benefits.

Another approach that can be considered is offering official recognition, with plaques or certifications, to businesses that have successfully implemented ESG or an equivalent. As government recognition and public acknowledgement would add value to their business, this incentive will motivate local companies. Correspondingly, this will assist Brunei in fulfilling SDG 2030 and Wawasan Brunei 2035, thus fostering a culture of sustainability within the country.

3.5 The challenges of implementing ESG in the halal industry in Brunei Darussalam

While incorporating ESG in the halal industry is vital, obstacles in this area must be addressed.

1) The market in Brunei in comparison to other ASEAN countries

Although Brunei is relatively larger than Singapore, the two countries have a considerable gap. While the population in Singapore is at millions, Brunei's population has barely reached half a million as of 2023 (Department of Economic Planning and Statistics Brunei, 2023). Due to this, the purchasing power in the country is relatively low as the F&B industry sales have only reached approximately BND100 million (Department of Economic Planning and Statistics Brunei, 2024), in comparison to Singapore's SGD955 million (Department of Statistics Singapore, 2024). It is important to note that this value may also be due to higher tourist numbers in Singapore than in Brunei. Nonetheless, the lower purchasing power is vital to address as ESG will require company

sacrifices. Although the ABAC MSME ESG and Sustainability Framework approach is applied with cost-effective measures, certain costs are inevitable with sustainability. Whether manpower or financial costs, these will ultimately affect the company and the customers. Thus leading to price increments that lessen its affordability for consumers and lower the purchasing demographic. With Brunei's more minor market condition, this can threaten the Bruneian economy if left unsolved.

2) The unemployment issue in Brunei

Environmental sustainability is crucial, but so are the social and governance aspects. Based on the statistics mentioned previously in Brunei, which shows a positive rank, it is possible that the reality for the people is not as optimistic. From 2022 to 2023 alone, the country has encountered a 0.1% increase in the underemployment rate (UER) (Department of Economic and Statistics Brunei, 2023). This could reflect that social and governance aspects are not realistically well-implemented according to expectations. It is crucial to tackle this challenge as it also concerns the halal industry in Brunei, which is also one of the industry's stakeholders.

In an article by The Scoop (2020), Brunei relies on foreign workers, especially in construction and blue-collar industries. Even in the article by Cheong *et al.* (2016) as part of the 'Foresight Study Project' by the Centre of Strategic and Policy Studies (CSPS): 'high unemployment' was ranked second in the 'prioritised trends and emerging issues' category by 107 responses. With this, 'community disintegration' was also included in the list at seventh rank with 32 responses. This refers to the increase in hostile environments, such as the rise in family conflict or difficulties for marginalised youths to integrate with society (Cheong *et al.*, 2016). With the emergence of these issues in Brunei dating back almost a decade ago with a continued drop, the government needs to provide a more proactive and realistic action plan to tackle the root cause of this issue, including considering the public's views. Reducing the unemployment rate, especially youth unemployment, can provide a positive spillover effect on other aspects of the country, such as increased purchasing power. Alongside this, there is also the possibility for an expansion in industries due to the higher demand for goods and services in Brunei Darussalam.

3) ESG is usually more focused on developed countries.

Like the adoption of sustainability concepts, they are prioritised mainly by developed countries. This refers to the advantage of having advanced technologies, adequate populations and a stable economy that allows ESG implementation to be smoother. Meanwhile, currently, Brunei possesses an economic reliance on the oil and gas industry (Sulaiman *et al.*, 2023), which is not ideal for the country long term. Hence, ESG might not be the primary decision businesses will make. While Brunei is considered a high-income country due to its high GDP per capita, it is still considered a developing country. Thus, Brunei may not yet be ready for full ESG implementation due to potential insufficient infrastructure and other issues that can overshadow the need for ESG.

To illustrate understanding, a comparison can be made between the global scenery and Brunei's local businesses. For

COMMITMENT	KEY PERFORMANCE INDICATOR	2021	2022	2023
We aim to reduce our greenhouse gas (GHG) emissions by 20% by 2025 and 50% by 2030 from 2018 levels, on the road to net zero by 2050 at the latest	Net reduction of GHG emissions vs. 2018 baseline[1] (%)	–	–	**13.58%**
We aim to achieve and maintain 100% assessed deforestation-free primary supply chains (for meat, palm oil, pulp and paper, soy and sugar) by 2022 and 2025 for cocoa and coffee	Primary supply chains for meat, palm oil, pulp and paper, soy and sugar assessed as deforestation-free (%)	97.2%	99.1%	**97.9%**
	Primary supply chains for cocoa and coffee + meat, palm oil, pulp and paper, soy and sugar assessed as deforestation-free (%)	–	–	**93.4%[2]**
By 2025, we aim for 20% of our key ingredients to be sourced from farmers adopting regenerative agricultural practices, and 50% by 2030	Key ingredients sourced from farmers adopting regenerative agricultural practices[3] (%)	n/a	6.8%	**15.2%**
We aim to reduce water use in our factories by 6 million m^3 between 2021 and 2023	Water use reduction in factories (million m^3)	2.30	2.38	**3.00**
By 2030, we aim for 100% of key ingredient[4] volumes to be Responsibly Sourced[5]	Key ingredients Responsibly Sourced (%)	16.3%	22%[6]	**36.2%**
	Number of servings of affordable nutrition with micronutrient fortification (MNF) (billions)	128.4[7]	129.2	**127.6**
By 2025, we aim to design above 95% of our plastic packaging for recycling and continue to work toward 100% being recyclable or reusable	Plastic packaging designed for recycling (%)	74.9%	81.9%	**83.5%**
By 2025, we aim to reduce virgin plastics by one third, versus our 2018 baseline	Virgin plastic reduction versus 2018 baseline (%)	8.1%	10.5%	**14.9%**
By 2030, our ambition is to help 10 million young people around the world have access to economic opportunities	Millions of young people around the world with access to economic opportunities since 2017	3.8	5.6	**7.7[8]**
	Management positions held by women (%)	–	–	**46.4%[9]**

Figure 2: Nestlé's Sustainability Report 2023 summarised sustainability key performance indicators (KPIs). Source: Nestlé, (2024). Creating shared value and sustainability report 2023.

example, Nestlé is a globally renowned brand that produces products such as Maggi and Nescafé. Additionally, they have implemented ESG practices, and their Malaysian counterpart (Nestlé Malaysia) is also certified halal by the Department of Islamic Development Malaysia (JAKIM) (Nestlé (Malaysia) Berhad, n.d.). In its Sustainability Report 2023, the brand has outlined its commitments and key performance indicators from 2021 to 2023 (See Figure 2). With 270,000 employees at their perusal (Nestlé, 2024) and billion figure scale, the brand can effectively execute its ESG adoption. Unlike these large corporations, MSMEs possess capability and resource limitations. Thus, although the implementation is possible, it would not be at the same level. Correspondingly, Brunei faces similar barriers to its adoption compared to its advanced neighbouring countries like Singapore and Malaysia.

Therefore, although ESG is vital for its economy and the growth of the halal industry, it requires the cooperation of all stakeholders, including the government, businesses, and consumers. ESG principles can be effectively adopted by seeking a balanced, practical, scalable solution.

However, it is to be noted that the above three challenges are mostly based on the researcher's observation of the environment surrounding ESG and potential hesitancy for its implementation. These challenges have also been reiterated as commonly rising issues for its citizens. Nevertheless, these do not dictate all of the challenges for ESG and halal in Brunei, which would require further in-depth research with multiple stakeholders to fully grasp it in its entirety. Thus, a whole-of-nation and government approaches must be taken to derive an appropriate solution suitable to everyone's needs at best.

4. Conclusion

In conclusion, despite limited data available on ESG in Brunei Darussalam, there are clear approaches that the stakeholders can be taken for its integration. It is also essential to increase efforts and explore different approaches to successfully incorporate ESG initiatives into Brunei Darussalam, particularly the halal industry. As demonstrated in other countries, incorporating ESG principles will positively impact the nation, people, and industries.

With ESG's three pillars, environmental, social and governance, the halal industry in Brunei can reap the benefits of incorporating its initiatives. Even if only one of the three pillars is adopted initially. As a result, this can contribute to Brunei Darussalam's potential to become a leading regional halal hub. However, for its realisation, it is essential that all stakeholders, government or private sectors, contribute, collaborate and encourage halal industry players to incorporate ESG into their business.

Furthermore, incorporating ESG principles is essential in diversifying Brunei's economy and reducing its reliance on oil and gas. Hence, the government should continue to self-assess its ESG strategies and address the challenges identified in this paper: the limited market size, the unemployment concerns, and the perceptions of ESG as a practice for developed countries. Nonetheless, adopting ESG principles is possible within the halal industry through resources from ABAC and UNDP.

It is also essential to recognised that this research has limitations, mainly due to the lack of data on ESG in Brunei's halal industry and the limited awareness of ESG compared to SDGs. Therefore, to address these gaps, future research should be done on the population's awareness and industry standards. This also includes gathering halal industry players in Brunei to determine their understanding of ESG. Through this, any future short-, medium-, and long-term plans and initiatives can be identified and created as part of a whole-nation approach.

By addressing these gaps and implementing comprehensive strategies, Brunei can foster a sustainable halal industry that meets global ESG standards and contributes to national development goals such as Wawasan Brunei 2035.

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HALALSPHERE
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A conceptual paper on the impact of technological innovations on halal SMEs supply chain performance: a mediating role of sustainability practices

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Abstract

In recent times, business environments have witnessed a surge in the usage and adoption of technological innovations to boost sustainability and resilience. This has shaped Malaysian government policies targeted at enhancing strategic or high impact industries where halal SMEs feature prominently. Also, technology and sustainable practice-related challenges hindering the Supply Chain Performance (SCP) of halal SMEs have been identified. However, available studies on halal SMEs do not cover the role of Technological Innovation (TI) on the SMEs' SCP and the significance of Sustainability Practices (SP) in this relationship. Also, relatively few studies analyse technological innovation in halal SMEs. The objectives of this conceptual paper are: to explore the impact of technological innovation on halal SMEs' supply chain performance and the mediating role of sustainability practice in the practice; and propose a conceptual framework whereby the effects of technological innovations on halal SMEs' supply chain performances are mediated by sustainability practices. Relevant extant studies in academic journal articles housed in various popular databases, such as Scopus, Emerald, Elsevier, etc., were comprehensively reviewed and incorporated into this study. The proposed model has potential to provide empirical data on the subject areas. The study suggests a tentative research agenda for future studies to achieve halal SMEs' efficient, flexible, competitive, and sustainable supply chain performance through effective interactions of technological innovations and sustainability practices.

1. Introduction

Since the COVID-19 pandemic, technological innovations have revolutionised all industries. There has been a surge in the usage and adoption of technological innovations to boost sustainability and resilience in the uncertain environment, with immense impacts on the supply chain (Ali *et al.*, 2021; Alraja *et al.*, 2022; De *et al.*, 2020; Hajar & Hadi, 2021; Kazancoglu *et al.*, 2023; LaBerge *et al.*, 2020). The significance of technological innovation within the supply chain cannot be overemphasised, as it promises to boost diversification and resilience during global supply chain disruptions (Rampersad *et al.*, 2020). Also, traction towards globalisation, pressure for more environmentally sustainable operations, and the need for improved general supply chain performance have intensified technological innovation drives (Talib *et al.*, 2022). These have driven scholars and practitioners to establish viable supply chain services to rejuvenate the industry, leading to technological innovation in halal logistics and supply chain management (Ahmad *et al.*, 2023; Talib *et al.*, 2022).

Meanwhile, halal SMEs represent 80% of the total SMEs in Malaysia, according to JAKIM. The halal industry (where halal SMEs play critical roles) has been positioned to play vital roles in actualising the economic goals of the Twelfth Malaysian National Development Plan. Malaysia ranked the world's top halal industry country (Dinar Standard, 2021), has realised the enormous economic potential that still exists in the halal industry and has developed the Halal Industry Master Plan 2030 (HIMP 2030). This plan 'was developed to catalyse Malaysia's strengths towards the development of its halal industry holistically' and identifies an estimated 80% gap between demand and production of global halal products. Also, among the five key target outcomes that will drive HIMP 2030 is 'having a robust and diversified domestic halal industry' (Industry *et al.*, n.d.), where the role of halal SMEs is indispensable. Malaysian halal SMEs can leverage this gap and opportunities by improving their supply chain performance with quality technological innovation and sustainability practices.

As Malaysia still trails in innovation and technology adoption behind top Asian countries such as Japan, South Korea, Singapore, and other high-income countries, its halal industry must be strengthened with entrepreneurial technological innovations (Razak *et al.*, 2018; Salaheldeen & Battour, 2024). Hence, the dominance of halal SMEs in Malaysia's SME sector indicates that halal SMEs are not free from technological innovation delinquencies and related challenges identified with general SMEs in Malaysia. Consequentially, despite halal SMEs' strategic importance and contributions to the Malaysian economy, these challenges may threaten their supply chain performance, especially amid the quest for sustainable business practices. In the literature some of the constraints to

technological innovation have been identified in general SMEs and halal SMEs in particular may not be immune to them as well. Amongst these are poor government support, quality of human resources, funding of technological innovation, etc. (Ali *et al.*, 2021; Indrawati *et al.*, 2020; Khusna Mustafa *et al.*, 2018).

Meanwhile, numerous halal SMEs and industry supply chains have peculiar challenges and issues that can be overcome with technological innovations. These include complex management of warehousing and terminals; the lack of trust and knowledge (integrity); perceived risk; difficulty in obtaining *Shari'ah*-compliant funding; multiple regional and global halal standards; and others that are directly related to the halal matters- non-segregation, concerns and possible regulation of rapidly developing genetically engineered or edited/synthetic genomes (man-made designer microorganisms and plants); food traceability issues and cross-contamination of halal-*haram* goods in supply chain processes etc. (Ahmad *et al.*, 2023; Dashti *et al.*, 2024; Elasrag, 2016; Mahidin *et al.*, 2017). Hence, to overcome these challenges and issues, halal SMEs, like other SMEs, are expected to capitalise on constant technological innovations to be more resilient and competitive and improve their supply chain performances (Alraja *et al.*, 2022; Dashti *et al.*, 2024; Indrawati *et al.*, 2020). However, technological innovations are not without their impacts or risks on the sustainability practises of enterprises (Ahmad *et al.*, 2023; Zaynullina, 2021). As part of their social responsibility, organisations must adopt environmentally friendly and technologically advanced approaches that result in sustainable performance (Alraja *et al.*, 2022).

Furthermore, there is an uptick in research on entrepreneurship and sustainable innovation. Still, there is a dearth of research on increasing sustainable innovation in the Malaysian and global halal industry (Salaheldeen & Battour, 2024). Also, relatively few studies have analysed technological innovation in SMEs. Most research on innovation was focused on large companies, leaving exploration of the impacts of innovation on SMEs, especially in developing countries, at a very low level (Bigliardi & Galati, 2016; Osman & Abbas, 2016; Radicic & Petković, 2023). These are indications that available studies on halal SMEs do not cover the influence of technological innovation on sustainability practices and their effect on SMEs' supply chain performance (Alraja *et al.*, 2022). Hence, the model proposed by this paper has the potential to provide an analytical focus on the significance and impacts of technological innovation on individual elements of SMEs' operational supply chain performance.

Given the significance and potential of technological innovation in providing a remedy to challenges, limitations, and other matters that are peculiar to halal SMEs, this conceptual paper is intended to explore the impact of technological innovation on halal SMEs' supply chain performance while identifying the mediating role of sustainability practice; and propose a conceptual framework whereby the effects of Technological Innovations (TI) on halal SMEs' Supply Chain Performances (SCP) is mediated by Sustainability Practices (SP). Hence, an explorative literature review was conducted, and a conceptual framework was proposed. For future research, the paper designed and suggested a model where the impacts of technological innovation on halal SME supply chain performance are mediated by sustainability practice.

The originality of this conceptual paper lies in proposing a model that attempts to examine how sustainability practices will mediate the impacts of technological innovations on the supply chain performance of halal SMEs. Hence, this study has engendered an effort to fill the gap of exclusion of the mediating and moderating effects of key variables in entrepreneurship, sustainable innovation, and supply chain identified in the body of literature (Ismail, 2022; Salaheldeen & Battour, 2024).

2. Literature review

2.1 The context of the study –Malaysia halal industry

In Malaysia, SMEs have always been identified as central to the country's national development (Tahir *et al.*, 2016). SMEs account for 97.4% of the country's overall establishments, contributing to 47.8% of total employment and 37.4% of GDP (DOSM, 2022). the Twelfth Malaysian National Development Plan (2021-2025) 'focuses on restoring the growth momentum of key economic sectors, and propelling strategic and high impact industries as well as micro, small and medium enterprises (MSMEs) to realign growth in a sustainable trajectory as well as strengthening Malaysia's position in the global supply chain'. Also, the national development plan has been designed to boost the halal industry among eight strategic and high-impact sectors identified by the Malaysian government (Economic Planning Unit, Prime Minister's Department, 2021). According to the government, the industry's development will be accelerated through the Halal Industry Master Plan (HIMP) 2030). This plan outlines seven strategic thrusts to produce high-quality products and services along the halal supply chain (Marketing-Interactive.com, 2021).

Significantly, 'accelerating technology adoption and innovation' features among the four catalytic policy enablers of the Twelfth Malaysian National Development. According to the Malaysian government, this is essential because the COVID-19 pandemic has significantly altered business operations, changed how people interact and accelerated digital technology adoption (Economic Planning Unit, Prime Minister's Department, 2021). Hence, according to the plan, advanced technologies, digitalisation, and niche capabilities will be leveraged to enhance the contribution of strategic and high-impact industries and activities to the economy.

In addition, advancing sustainability forms the third theme of the Twelfth Malaysia National Plan. This focuses on advancing green growth, enhancing energy sustainability, and transforming the water sector to ensure the nationwide shift to more sustainable economic practices and lifestyles that value natural endowments and environmental health. This addresses climate change, unsustainable consumption and production practices, and biodiversity loss (Economic Planning Unit, Prime Minister's Department, 2021).

2.2 Technological innovations in the supply chain domain

Due to innovation's multifaceted nature, there are many definitions of the concept, but the inextricable relationship between innovation and entrepreneurship is very instructive. Joseph Schumpeter's (1934) equating of entrepreneurship to innovation is more significant and appropriate today than ever (Śledzik, 2013). SME technological innovation refers to both revolutionary initiative (creation of new technology) and modification - making significant improvements on existing technologies (Indrawati *et al.*, 2020; Salaheldeen & Battour, 2024). The former and the latter include discovering and

applying new processes or methods, introducing new products or services, exploiting new opportunities, opening new markets, creating new industry structures, improving existing products and services, modifying existing processes and products, increasing economies of scale, etc. (Indrawati *et al.*, 2020; Śledzik, 2013). Irrespective of the way and manners of its definition, technological innovation revolves around input, process, and output as they relate to product and organisation.

Technological innovations have attracted tremendous attention due to their vast benefits and significance. These include lowering production costs, improving the quality of goods, improving firm competitiveness, impacting the complex and constantly changing business environment, and catering to organisations' need for flexibility and responsiveness (Hajar & Hadi, 2021; Hussain *et al.*, 2022; Ifenthaler *et al.*, 2021). It is believed that technologies have the potential to affect every aspect of businesses or organisations, produce significant improvements, and be a panacea to challenges in supply chain and logistics management (Ali *et al.*, 2021; Hajar & Hadi, 2021). It revolutionises the operational process for small-scale industries by aiding process integration, digitisation, automation, and efficient resource use. This leads to substantial performance improvements across supply chain processes—procurement, production, inventory management, and retailing (Hajar & Hadi, 2021; Hussain *et al.*, 2022). Technological developments also cause changes in organisational experiences, such as the capability to produce new goods and services while enabling people to learn new things, communicate with others, and create and share innovations (Celtekligil & Adiguzel, 2019). Hence, halal SMEs cannot afford to be indifferent to the global technological revolution if they want to improve their supply chain performance and be more competitive, resilient, and sustainable.

The spate and rate of new types and models of technologies over the past few decades is high, hence the rapidly changing faces of the business world and the redefining of ways supply chain operations are conducted. The first three industrial revolutions heralded by advances in mechanisation, electricity, and IT were quickly followed by innovative technologies in the manufacturing environment, which brought about the fourth industrial revolution – Industry 4.0. This refers to a new era of business process decentralisation aided by technological advances where information about actual products is linked to web-based applications and integrated into the production process (Ali *et al.*, 2021; Hajar & Hadi, 2021). Machine to Machine (M2M) communications, Internet of Things (IoT), Cyber-Physical Systems (CPSs), artificial intelligence, and Big Data Analytics (BDA) have created a business environment where employees, machinery, devices, and enterprise systems are connected through CPSs and the Internet (Hajar & Hadi, 2021). Various cutting-edge or disruptive technological innovations have transformed the supply chain field. These include containerisation, Electronic Data Interchange (EDI), Radio Frequency Identification (RFID), Quick Response (QR) codes, Smart packaging, GPR tracking, robotic and drone technologies, and more recent applications of big data, blockchain technology, and electric vehicles (Ali *et al.*, 2021; Hajar & Hadi, 2021; Talib *et al.*, 2022). Today, companies are embracing advanced technological innovations associated with the fourth industrial revolution by heavily investing in automation and robotics. These innovations bring significant benefits to manufacturing and enable extensive process integration (Hajar & Hadi, 2021).

The application of e-business technologies has assisted many companies in streamlining their business processes and improving operational performance through process integration (Hajar & Hadi, 2021; Hussain *et al.*, 2022). The steady increase in business systems automation leading to efficiency, productivity gains, and improved quality encourages organisations to extend technological innovations in operational arenas to other organisational areas, such as supply chain management (Hajar & Hadi, 2021). Technological innovations have enabled innovative process management, provided new paradigms for industrial management, and significantly improved the nature and quality of products and services provided by organisations (Ali *et al.*, 2021; Hajar & Hadi, 2021; Hussain *et al.*, 2022).

2.3 Technological innovations and halal SMEs: opportunities and challenges

2.3.1 Opportunities

In addition to their crucial role as a significant source of employment and economic growth, SMEs are also regarded as a source of technology adoption and innovation (Ngah *et al.*, 2022). This may be due to SMEs' ubiquitous significant role in all areas of human needs that businesses cater to through technology. Organisations, including SMEs, have realised the significance of technological advances and considered technology a potent strategic weapon for ensuring sustainable supply chain performance (Hajar & Hadi, 2021). However, there is limited extant research regarding innovation in the halal business model, though it inherently supports innovation for competitive advantage and business sustainability (Salaheldeen & Battour, 2024). Salaheldeen & Battour (2024) is one of the few recent studies in this area. They investigate the relationships between halal entrepreneurial success, innovation capability, and sustainable innovation in the halal industry. The study posits that innovation capability mediates between halal entrepreneurial success and sustainable innovation. Hence, Battour (2024) suggests the significance of technological innovation in halal supply chain performance. Also, Ali *et al.* (2021) study proposes a sustainable blockchain framework for the halal food supply chain (SC) after conducting an exploratory study using case studies. Their findings indicated that blockchain, as a disruptive technology, can help halal food SMEs achieve SC transparency. Similarly, Rejeb *et al.* (2021) conducted systematic literature on integrating the Internet of Things (IoT) in the halal food supply chain (HFSC), with over seventy-three (73) papers analysed, using both bibliometric techniques and in-depth content analysis. The study's findings show that IoT's significant benefits include: 'traceability of products, enhancement of supply chain efficiencies, facilitation of livestock management, authentication of foods' halal status, and monitoring of halal certifications'.

However acccording to Ahmad *et al.* (2023), the study of the key factors for Green Supply Chain and Logistic Management (GSCLM) in the context of Malaysia's halal food industry indicated that technology had a negligible effect on GSCLM. The outcome of this study regarding the insignificant effect of technology on the supply chain is inconsistent with most studies relating to technological innovation and supply chain. This inconsistency may be due to the study's limitations and may not apply to halal SMEs, which were not indicated as the sampled or targeted population in the study.

Expansion of supply chains comes with more complexity, which requires advanced technology, regulations, and

certifications to ensure the quality and integrity of imported food products, for example (Dashti *et al.*, 2024). As mentioned, one of the technological innovations impacting supply chain values is blockchain technology, though its adoption and its benefits have not been fully realised, especially for SMEs (Ali *et al.*, 2021). Halal SMEs can benefit from blockchain-based halal payment services and information sharing, which is currently being practised in the halal industry through the digitisation of halal certificates (Ali *et al.*, 2021; Salaheldeen & Battour, 2024). Blockchain benefits the primary goal of the halal supply chain, which is assuring consumers of full-scale halal integrity while addressing the key aims of supply chain management, such as risk mitigation flexibility, quality, and sustainability (Ali *et al.*, 2021). Therefore, this underscores the significance of blockchain technology in halal supply chain research related to fraud, transparency, traceability, delivery, quality, safety, security, and sustainability due to their impacts on health and religious concerns for consumers (Ali *et al.*, 2021). Inadequate adoption of technological innovations such as blockchain may jeopardise the ultimate aim of the halal industry, while its successful implementation and adoption will enhance visibility, transparency, and traceability (Ali *et al.*, 2021).

Besides blockchain technology, many other innovations possess immense potential benefits to halal supply chain performance. Literature by Ali *et al.* (2021), Dashti *et al.* (2024), Hajar & Hadi (2021), Salaheldeen & Battour (2024) and Suhartanto *et al.* (2024), identifies the following:

i. Quick Response (QR) Code: This is a very affordable and effective way of traceability that can provide halal consumers with vital information like country of origin. It is different from conventional pre-packaged food labelling complexity.

ii. Radio Frequency Identification (RFID tag: contains specific information to identify leaks in the distribution network, giving the capacity to process large volumes quickly and efficiently.

iii. IoT-based business solutions enable smart retailing by tracking and tracing platforms through real-time visibility; hence, they can manage uncertainties and risks associated with the pathways of items in the halal food supply chain, including communication risks.

iv. A GPS track-and-trace system detects delays in the transportation system, which may prevent halal product counterfeiting in the logistic process while significantly impacting inventory management.

v. Smart packaging can be integrated with wireless communication and cloud service to activate real-time monitoring of halal products and services, thus providing transparency of product movement in the supply chain.

vi. Big Data Analysis (BDA) services: could be used to maximise competitive advantage through transparency while enabling supply chain innovation integration competencies and resources.

vii. 3D printing and virtual and augmented reality can also be implemented for halal ventures.

2.3.2 Challenges

However, despite technological innovation's numerous benefits and opportunities, its applications in SMEs, particularly halal SMEs, face some challenges (Ali *et al.*, 2021; Indrawati *et al.*, 2020; Rejeb *et al.*, 2021). While the most significant inhibiting factor is the funding of technological innovation (Indrawati *et al.*, 2020), other obstacles include poor government support, quality of human resources, economic conditions and business partners, technological complexity, lack of capability, cost efficiency, and return of investment uncertainty, which is also an essential concern in the innovation adoption literature (Ali *et al.*, 2021; Indrawati *et al.*, 2020; Ngah *et al.*, 2022). The complexity of some technological innovations is another major obstacle confronting SMEs in their efforts to maximise the benefits of such innovations. Literature shows that firms prefer innovations that are simple, user-friendly, available, and specifically tailored; hence, SMEs are facing difficulties in adopting blockchain technology (Ali *et al.*, 2021; Ngah *et al.*, 2022).

Furthermore, technological immaturity, lack of user acceptance, and regulatory barriers also constitute challenges to halal SMEs' technological innovations, as many SMEs are low in sophisticated knowledge of IT and equipment (Ali *et al.*, 2021; Rejeb *et al.*, 2021). Due to their limited economic scale, halal SMEs cannot negotiate the unification of data formats and cannot outsource difficult and costly supply chain technological activities (Ali *et al.*, 2021). Also, the application of technological innovation among SMEs is still limited due to its high cost and uncertainty surrounding its return on investment—the price of the technology adoption may be higher than the product's value, making the investment raise costs without necessarily increasing revenue (Ali *et al.*, 2021; Indrawati *et al.*, 2020).

2.4 Supply chain performance

While enterprise performance has attracted considerable attention recently, SMEs' performance has become a significant concern for industrialisation and modern economies despite technological innovation's imperative role (Hussain *et al.*, 2022). Supply chain performance can be measured through cost, financial, and non-cost or non-financial metrics (Hajar & Hadi, 2021; Piprani *et al.*, 2020). Cost measures may include inventory and operating costs to fulfil cost efficiency goals, such as cost optimisation in production, warehouse, and logistics (Piprani *et al.*, 2020). Non-financial indexes include flexibility, reliability, responsiveness, customer satisfaction, innovation, time, availability, and information sharing (Hajar & Hadi, 2021; Kumar *et al.*, 2017; Piprani *et al.*, 2020). Hence, companies invest in technological innovations to build effective information-sharing and collaboration mechanisms and improve supply chain performance (Hajar & Hadi, 2021). Supply chain performance as a firm's non-financial performance can be measured by customer satisfaction, advanced technological innovation, and reduced production time (Hussain *et al.*, 2022).

2.5 Sustainability practices and technological innovation

Due to pressures from public policies, international environmental legislations, growing customer demand, and socio-environmental awareness, firms are increasingly inclined towards more sustainable and socially responsible practices

(Salaheldeen & Battour, 2024). Hence, incorporating technological innovations such as blockchain applications is appreciable, as they can aid the efficient use of resources, making sustainable performance a key feature in smart factories (Ali *et al.*, 2021; Hajar & Hadi, 2021). According to Alraja *et al.* (2022), this has led organisations to adopt environmentally friendly and technologically advanced approaches that result in sustainable performance. Sustainability policies are becoming more popular among SMEs because sustainable practices are equally important as innovation in compliance for in today's highly competitive business environment (Du *et al.*, 2022). By prioritising technological innovations, enterprises are changing their products and process portfolios, proactive and involved in environmentally friendly practices to sustain themselves (Alraja *et al.*, 2022)Moreover, halal production is considered sustainable due to its specific processes and goals of producing safe, high-quality products with intact consumer integrity. (Ali *et al.*, 2021).

It is also believed that transitioning to green could be implemented more successfully through advanced technological innovation. For instance, halal green supply chain and logistics, which involves cost reductions, raising the value to end consumers, and halal compliance without excluding profitability, may not be achieved without technological innovation. (Ahmad *et al.*, 2023). Quality assurance control (halal assurance systems) in the entire halal green supply chain management entails requirements such as saving output (non-toxic), proven harmful-free, hygienic, and lawfully permitted - which depend on technology such as radio frequency identification (RFID), and Artificial Intelligence (AI) (Ahmad *et al.*, 2023).

However, technological innovation is considered a "double-edged sword" due to its significant contribution to climate change, ecological imbalances, and worsening pollution while effectively solving environmental and sustainable development problems. (Irfan *et al.*, 2022). Hence, Du *et al.* (2022) suggested that SMEs dedicate more resources towards sustainable development by adopting recruitment strategies based on environmental standards. Other measures suggested to aid SMEs' sustainability performance include higher investment in research and development to improve ecological efficiency, updated technology in the production process and service delivery, and promoting eco-friendly services and goods via environmentally conscious digital platforms (Du *et al.*, 2022).

2.6 Conceptual framework of the study

The conceptual framework in Figure 1 was developed in line with the evidence in the reviewed literature. It depicts the relationship between this study's independent, mediating, and dependent variables. The framework indicates that technological Innovation (TI) - the independent variable, has a positive and significant relationship with Supply chain Performance (SCP) - the dependent variable, through the mediating role of Sustainability Practice (SP) - the mediating variable.

3. Research design and methodology for future research

To achieve the research objectives of this study, extant studies found relevant from academic journal articles housed in various popular databases, such as Scopus, Emerald, Elsevier, etc., were comprehensively reviewed and incorporated into this study (Jaiyeoba & Azam, 2023; Showole & Jaiyeoba, 2024). In congruence with the proposed conceptual model, it is suggested that future investigations be conducted using a positivist research paradigm. This approach will enable future research to objectively test causal relationships among the variables in the developed model (Khaldi, 2017). The positivist research paradigm is based on the ontological assumption of a reality independent of the observer (Dahler-Larsen, 2015): realities of the world is objective and knowable in its entirety; a researcher can be separated from the research's object; hence, their task is to describe and analyse this reality in a neutral way (Khaldi, 2017). Future researchers should also consider the ethical and procedural implications of the positivism paradigm, such as confidentiality, informed consent, and avoidance of coercion (Dahler-Larsen, 2015).

In addition, future research is expected to develop a questionnaire based on the existing literature to consider all model variables. To investigate these variables, the questionnaire should be employed to collect data from employees of halal SME owners and managers. The procedure for data collection could be a probability or non-probability sampling approach using a valid instrument (Likert scale) that measures the impacts of Technological Innovation (TI) on the supply Chain Performance (SCP) of halal SMEs. The sample population to be studied by future research should be SME owners and managers with at least three years of experience and currently working in the halal SME sector. A sample size between 100 and 500 participants is recommended for structural equation modelling, which is appropriate for the proposed model (Hair *et al.*, 2018; Jaiyeoba *et al.*, 2022; Memon *et al.*, 2020).

4. Theoretical implications and practical implications

One of the theoretical implications of this conceptual paper is its potential to address some vital gaps identified in halal SMEs' supply chain literature. Available literature has revealed that studies on SMEs do not cover the effects of halal SMEs' technological innovation on sustainability practices and their supply chain performance (Alraja *et al.*, 2022). Most research on innovation has been focused on large companies; relatively few studies analyse technological innovation in SMEs; exploration of impacts of innovation on SMEs in developing countries is at a very low level (Osman & Abbas, 2016; Radicic & Petković, 2023).

Figure 1. Conceptual framework.

Also, this conceptual paper and proposed models will contribute more to the literature and knowledge on supply chain theories, such as Resource Base View and Dynamic Capabilities theories. These theoretical frameworks treat technological innovations as a valuable resource and a dynamic capability that enables SMEs to respond and adapt to changing market and environmental and social conditions, thereby contributing to long-term competitiveness and improved supply chain performance. Also, SMEs' resource base and dynamic capabilities will be further enhanced when sustainability practice mediates the relationship between technological innovation and supply chain performance.

As part of the practical implications, this paper will spur further research that enhances understanding of how technological innovation impacts halal SMEs' supply chain performance and the mediating role of sustainability practices leading to their competitive advantage. This study has shed light on how halal SMEs can leverage technological advancements and integrate sustainability practices to achieve improved efficiency, supply chain-associated cost reductions, and market differentiations. More research based on this proposed model will help halal SMEs strengthen their supply chain integration - communication, coordination, and information sharing with suppliers and customers. Also, studies on sustainability practices can further improve halal SMEs' resource optimisation, reduce transaction costs by mitigating risks linked to environmental regulations, and boost social compliance and stakeholders' expectations management. Hence, sustainability practices as a mediator will enhance environmental and social performance by reducing halal SMEs' carbon footprints, minimising waste, and promoting fair labour practices.

In addition, research outcomes from this conceptual paper can provide policymakers with quality data and information about the potential benefits of promoting technological innovation and sustainability practices among halal SMEs. This will facilitate designing, formulating, and implementing rich policy frameworks, incentives, and other initiatives that will motivate halal SMEs to adopt innovative technologies and sustainable practices. for instance, future research derived from this conceptual paper can enhance the implementation of the Twelfth Malaysian National Development Plan (2021-2025), which 'focuses on restoring the growth momentum of key economic sectors, and propelling strategic and high impact industries as well as micro, small and medium enterprises (MSMEs) to realign growth in a sustainable trajectory as well as strengthening Malaysia's position in the global supply chain' (Economic Planning Unit, Prime Minister's Department, 2021). The plan outlines seven strategic thrusts to produce high-quality products and services along the halal supply chain. (Marketing-Interactive.com, 2021). Hence, the technological innovations and sustainability practices forming the crust of this study are essential to the Twelfth Malaysian National Development Plan.

Generally, this conceptual paper on the impact of technological innovation on halal SMEs' supply chain performance with sustainability practices as a mediator has wide-ranging significance. It can improve competitiveness, sustainability, and resilience in halal SMEs while contributing to broader socio-economic growth and environmental stewardship by aiding the design of effective data-based halal SME policies.

5. Conclusions

The researchers have proposed a model and conceptual framework with the assumption that halal SMEs' Technological Innovation (TI) positively impacts Supply Chain Performance (SCP) with Sustainability Practices (SPs) as a mediating variable in the established relationship. After reviewing relevant studies, the researchers have shown how technological innovation can contribute to halal SMEs' supply chain performance. Similarly, researchers have revealed the importance of sustainability practices in mediating the relationship between technological innovations and halal SME supply chain performance. Building on this model proposed by the researchers and various empirical findings mentioned so far, this study has demonstrated how the developed conceptual model and the relationship therein can enhance the supply chain performance of halal SMEs by contributing to their competitiveness. Concerning the limitation of this study, the developed conceptual framework has not been tested empirically; the researchers call on future studies to collect data to test the established model empirically. Also, this study has mainly identified the impact of technological innovations on halal SME supply chain performance with the mediating role of sustainability practices; future research may incorporate other relevant variables while investigating the suggested model.

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HALALSPHERE
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Exploring factors behind whistleblowing intention among employees in the Malaysian halal food manufacturing sector

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Abstract

Whistleblowing serves as a crucial tool to enhance the security of the halal food supply chain. Despite its importance as a monitoring tool, research on whistleblowing intentions within halal-certified food companies has been limited. This study explores employee awareness and whistleblowing intentions by conducting semi-structured interviews with 16 informants and using thematic analysis guided by the Theory of Planned Behaviour (TPB). The findings show varying levels of employee awareness and knowledge of whistleblowing. Some employees have a clear understanding due to company policies and training, while others have an intuitive understanding of the concept despite limited exposure. As highlighted in the TPB, attitudes, subjective norms, and perceived behavioural control were found to influence whistleblowing intentions. Furthermore, factors such as organisational support, employee responsibility, religious obligation, seriousness of wrongdoing, knowledge, and the perceived authority of the complaint recipient also influenced whistleblowing decisions. These findings emphasise whistleblowing's complex interaction of individual, social, and organisational factors. While the whistleblowing framework is not new, this study's contribution lies in its application to halal-certified food companies, offering valuable insights for companies, regulators, policymakers, and academics in the halal sector.

1. Introduction

Nowadays, halal food products represent the primary sector of the halal industry. The halal market is no longer as niche as it was two decades ago. According to Abdullah (2018), the global halal market is estimated to reach an annual growth rate of 20%. This global market for around 1.8 billion Muslims worldwide has expanded beyond food and food-related products to other manufacturing sectors, including pharmaceuticals, cosmetics, health products, toiletries, medical devices, and service sectors (logistics, marketing, packaging, advertisement, and finance). Abdullah (2018) reiterates in his article that the increasing demand for halal products and services in Malaysia, with a population of around 35 million Muslims, is more than 60%.

The halal market has evolved significantly, shifting from primarily focusing on meeting Muslim communities' religious needs to attracting a broader audience. Increasingly, non-Muslim consumers are turning to halal products, driven by perceptions of cleanliness and hygiene that set them apart from conventional alternatives (Abderahman, Karim & Kevin, 2021; Abdul Talib *et al.*, 2008). This growing demand is reflected in the rise of halal-certified small and medium enterprises (SMEs), as highlighted in Abdullah's (2018) study, which shows an increase in the number of such businesses in Malaysia. The surge in halal-certified SMEs demonstrates the broader acceptance of halal products beyond religious considerations as they become more integrated into mainstream markets. This trend speaks to the evolving market and points to the economic opportunities for growth and job creation within the halal industry. As consumer awareness and demand for ethical products continue to rise, the halal market is poised for even more significant expansion in the future.

The potential benefits from local and global halal markets are vast, especially considering the strong demand for halal food. However, many of the key players in the industry come from non-Muslim-majority countries. For example, countries like New Zealand and Australia dominate the meat and poultry markets, leading the world in exporting halal meat. Similarly, Brazil and Argentina are the largest producers of poultry (Mujar & Hassan, 2016). Given this, Muslim-majority countries must recognise and capitalise on the global halal market's opportunities to secure leading positions. Collaboration among stakeholders—governments, academics, entrepreneurs, corporate industries, policymakers, and consumers—is essential to realise the market's potential.

One key step toward seizing these opportunities involves addressing the halal industry's issues and challenges. Among the most critical concerns are illegal, inappropriate, and fraudulent practices related to halal certification, food safety

and market regulation. As highlighted by Hauer (2017), some of the most notable fraud cases include using illegal dyes in chilli powder and adding melamine to high-protein feeds and milk-based products. A 2016 report by Chuah *et al.* (2016) revealed that 78.3% of processed meat products sold in Malaysia were incorrectly labelled, with only 21.7% accurately representing their content—additionally, Md. Ariffin *et al.* (2023) reported on an illegal meat cartel that affected Muslim consumers, as it involved repackaging meat imported from foreign countries, labelling it with a halal logo, and distributing it without approval from JAKIM officials. Another significant issue is the violation of food hygiene regulations, such as the tampering with food safety records, including slaughter dates, which was uncovered by whistleblowers (Hauer, 2017).

Loria (2017) reported that food fraud has cost the food industry around USD 30 to 40 billion annually. Not only does it lead to significant financial losses, but it also creates widespread panic, distress, and distrust among Muslim consumers. The lack of stringent regulations to tackle these issues exacerbates the situation. Consumers are increasingly sceptical about accepting halal-certified food products at face value, and food fraud harms not just the reputation of specific companies but also the halal industry as a whole. The erosion of consumer trust can potentially undermine the credibility of halal certifications, particularly in Malaysia.

Whistleblowing has emerged as a crucial countermeasure against the food industry's illegal, unethical, and fraudulent practices (Soon & Manning, 2017). According to Gerald Moy (2014), the International Labour Organisation (ILO) defines whistleblowing as the reporting of employees' illegal, dangerous, or unethical practices. In the context of the halal industry, whistleblowing is an essential tool to combat fraudulent and unethical practices, especially as the global halal market continues to expand rapidly. The financial losses and consumer distress caused by halal food fraud have undermined trust in halal certification systems, making it more difficult to ensure the integrity of halal products. Given these challenges, this study focuses on whistleblowing as a critical countermeasure. It aims to explore employee awareness and knowledge of whistleblowing in halal-certified food companies, using the Theory of Planned Behaviour to examine the factors that influence whistleblowing decisions—understanding how attitudes, social norms, and perceived control impact whistleblowing intentions will provide valuable insights into the behavioural drivers behind whistleblowing in the halal industry. Additionally, identifying other factors that affect whistleblowing will help formulate practical solutions to encourage reporting, thereby addressing the root causes of fraudulent practices and reinforcing trust in halal certifications.

2. Literature review

Whistleblowing is generally defined as the intentional revelation of information regarding significant activities perceived as dangerous, illegal, unethical, discriminatory, or otherwise indicative of misconduct. This revelation is typically made by current or former members of an organisation (Hersh, 2002). Whistleblowing can be considered internal or external, depending on the report's recipient. Internal whistleblowing occurs when misconduct is reported to individuals within the organisation, such as a direct supervisor (Zakaria *et al.*, 2016). Conversely, external whistleblowing occurs when misconduct is reported to third parties outside the organisation, such as the media, government officials, law enforcement, or concerned individuals (Zakaria *et al.*, 2016). Hayati and Wulanditya (2018) offer a broader definition, suggesting that a whistleblower can be any individual within or outside the organisation who possesses knowledge of the organisation's misconduct.

Companies often prefer internal whistleblowing to external whistleblowing to avoid reputational damage. Disclosing information to external parties can attract negative publicity and be perceived as a breach of employee obligations, violating written and unwritten contracts (Zhang *et al.*, 2009). In addition, whistleblowers may encounter legal repercussions, as external reporting can be viewed as a breach of loyalty to their employer. In some jurisdictions, such as Poland, this can result in dismissal or legal action against the whistleblower, complicating their careers (Kobroń-Gąsiorowska, 2022). In contrast, internal whistleblowing allows the company to manage issues discreetly, without external pressure, and address them before they escalate into more significant crises. Therefore, to prevent employees from reporting to external parties, transparent and accessible reporting channels must be available (Soon & Manning, 2017). Employees need to know how and where to report, with assurances that their information will be kept confidential.

Whistleblowing is now recognised as a vital component of food safety assurance and a last resort when other measures fail (Gerald Moy, 2014). Consequently, food manufacturers need strategies to ensure halal food safety, quality, and integrity and build trust in the expanding global halal industry (Loria, 2017). Halal-certified food companies benefit from early internal detection and prevention of illegal practices, avoiding issues like product recalls, profit loss, and damage to their reputation, trust, and brand value. This ensures that illegal and inappropriate practices in the halal food market and within companies can be addressed if not eliminated. Whistleblowers may resort to external reporting if reporting channels are absent or ineffective.

Ambali and Bakar (2013) highlight that awareness is the ability to perceive or be conscious of events, objects, or sensations, while knowledge refers to the understanding of a subject gained through experience or education. Awareness is the foundation upon which knowledge is built, and both are critical in fostering ethical practices within organisations. The effectiveness of whistleblowing as a tool for maintaining organisational integrity depends mainly on how well employees understand the processes and protections involved. When employees are aware of their rights and the available mechanisms, they are more likely to report unethical behaviour, thereby contributing to a culture of transparency and accountability, as Subaki *et al.* (2023) reported.

However, despite growing recognition of the importance of whistleblowing, research indicates that significant gaps in knowledge persist among employees. For instance, Subaki *et al.* (2023) highlight that many individuals are unaware of the formal processes and protections available for whistleblowers. This lack of awareness can deter employees from reporting misconduct, as they may fear legal repercussions, job loss, or social ostracism. Without a clear understanding of the whistleblowing process, employees may feel powerless or uncertain about how to proceed, leading to underreporting unethical behaviour.

Table 1: Demographic profile of informants

No.	Code	Position	Educational background	Food Industry Experience (Year)	Working in Current Position (Year)	Nature of business
1	AA_1	Admin Assistance	Diploma	>5	>5	Food
2	HE_1	Halal Executive	Degree	<2	<2	Food
3	IA_1	Inventory Assistance	Degree	<2	<2	Food
4	HE_2	Halal Executive	Degree	2 -5	2 -5	Food & beverages
5	HE_3	Halal Executive	Degree	2 -5	2 -5	Food & beverages
6	HE_4	QA cum Halal Executive	Degree	2-5	2-5	Beverages
7	HE_5	Halal Executive	Degree	2-5	2-5	Food
8	HE_6	Halal Executive	Degree	>5	>5	Food & beverages
9	C_1	Consultant Halal & Safety	Degree	2-5	>5	Consultation n
10	SHE_1	Senior Halal Executive	Degree	2-5	>5	Beverages
11	HoD_1	HoD, Ijazah Sarjana Muda Pengurusan Halal	Master	> 5	> 5	Education
12	HE_7	QA Executive	Degree	<2	2-5	Food
13	M_1	Manager, Sales & Marketing	Master	>10	>10	Food
14	D_1	Director	Master	> 10	> 10	Beverages
15	D_2	Director	Degree	>10	>10	Food
16	AD_1	Assistant Director	Degree	>10	>10	Food & beverages

Note: Code AA = Admin Assistance, AD= Assistance Director, C= Consultant, D= Director, HE= Halal Executive, HoD= Head of Department, IA = Inventory Assistant, M= Manager, SHE = Senior Halal Executive.

It is essential to recognise that knowledge alone is insufficient to encourage whistleblowing. Latan et al. (2019) point out that, despite increased awareness, fear of retaliation remains a substantial barrier to reporting misconduct. Even when employees are fully informed about the protections available to them, they may hesitate to blow the whistle if they believe their actions could result in negative consequences, such as being ostracised by colleagues, passed over for promotions, or even facing legal action. This suggests that a supportive environment is crucial for effective whistleblowing. Organisations must educate their employees and actively work to create a culture where whistleblowers are protected and valued.

The existing body of research on whistleblowing in Malaysia extensively examines factors influencing whistleblowing intentions across various sectors, including public organisations, government-linked companies (GLCs), and higher education institutions, emphasising personal, organisational, and legal dimensions. However, a critical gap remains in understanding whistleblowing within the halal industry despite Malaysia's role as a global hub—unique challenges, such as fraudulent halal certification and non-compliance with halal guidelines. While recent studies, like Yusoff (2023) and Abd Rashid *et al.* (2023), begin to explore whistleblowing intentions in halal contexts, these are limited in scope and lack qualitative insights. Moreover, the lack of awareness and understanding of whistleblowing mechanisms within halal-certified companies worsens the issue, highlighting the urgent need for research into employees' whistleblowing intentions. This research should be grounded in both theoretical frameworks and the ethical complexities of the halal industry to promote accountability and restore trust in halal certification.

3. Materials and methods

Qualitative in-depth interviews were selected as the optimal method for gathering data on individual perspectives and experiences, particularly when exploring sensitive topics (Mack *et al.*, 2005), such as whistleblowing. For this study, semi-structured interviews were conducted, guided by the Theory of Planned Behaviour (TPB) and informed by a literature review on whistleblowing. The interview protocol included questions on awareness and perceptions, experiences, and factors influencing whistleblowing, not only in line with TPB's focus on attitudes, subjective norms, and perceived behavioural control but also addressing other relevant factors that may impact employees' decisions to blow the whistle. Purposive sampling was employed as the sampling strategy. The informants included representatives from halal companies (n=14) and experts (n=2) to explore the factors influencing whistleblowing intentions comprehensively. Informants from halal companies were purposefully selected to ensure diversity in job positions and departments (e.g., halal executives, directors, administrators), capturing a wide range of perspectives and employee awareness and knowledge of whistleblowing. The interview sessions were recorded and transcribed, and thematic analysis was used to identify key themes within the

Table 2: Company profile of the informants from halal companies

Company	Nature of business	Company Type	Years of establishment	Company Category	No. of employees
A	Food	Private limited company	>15 years	Small enterprise	10-49
B	Food	Private limited company	>10 years	Small enterprise	10-49
C	Food	Private limited company	>20 years	Large enterprise	≥250
D	Food & Beverages	Private limited company	>20 years	Small enterprise	10-49
E	Food	Private limited company	>5 years	Small enterprise	10-49
F	Beverages	Private limited company	>5 years	Medium enterprise	50- 249
G	Food	Private limited company	>20years	Large enterprise	≥250
H	Food	Public limited company	>20years	Large enterprise	≥250
I	Beverages	Private limited company	>10 years	Large enterprise	≥250
J	Food	Private limited company	>20years	Large enterprise	≥250
K	Food	Private limited company	>20years	Small enterprise	10-49
L	Beverages	Private limited company	>10 years	Small enterprise	10-49
M	Food	Private limited company	>20 years	Large enterprise	≥250
N	Food & Beverages	Private limited company	>20 years	Large enterprise	≥250

data (Braun & Clarke, 2006). The Web version of ATLAS.ti was used to facilitate the data analysis.

4. Results and discussion

4.1 Informant demographic profile

The investigation into whistleblowing intentions was conducted among 16 informants (Table 1). The informants from certified companies included seven Halal Executives, one Senior Halal Executive, two Directors, one Assistant Director, one Manager, one Inventory Assistant, and one Admin Assistant. Additionally, perspectives from a halal consultant and an academician were included. Nine of the informants were female, and seven were male. Regarding educational background, most of the informants involved in this research have a degree (12) and a master's (3). One has a diploma. For working experience, most of the informants have been working in the food industry for 2–5 years; 3 have worked for more than 5 years; and 3 have worked in the food industry for less than 2 years. Meanwhile, 4 informants have worked in the food industry for more than 10 years.

The results from Table 2 indicate that most informants were from private limited companies (13 out of 14 companies) within the food or food and beverage sectors. Most of these companies have been established for over 10 years and fall into either small (with 10-49 employees) or large enterprises (with 250 or more employees). Only one company was classified as medium-sized enterprises. There was only one public limited company represented in the sample.

4.2 Awareness and knowledge about whistleblowing

The interview with employees from this industry reveals a spectrum of familiarity with the term 'whistleblowing' and its implications. These interviews underscore the varying levels of awareness and the underlying understanding of the concept. This familiarity appears to be closely linked to their work environments, mainly whether their companies have established whistleblowing policies. For instance, employees from companies with formal whistleblowing mechanisms demonstrate a higher awareness and understanding of the term. An informant emphasises that "all staff know about whistleblowing'" due to the regular training sessions and email communications about the company's policy.

> *"In my company, we have indeed implemented a whistleblowing policy; all staff know about this whistleblower; whistleblowing everyone knows. If we go in, we will have one training; even if there is no training, the company will blast an email to all staff regarding this whistleblowing." (HE_6)*

Similarly, another informant notes that his familiarity with whistleblowing dates back to the beginning of his career 12 years ago, with the company reinforcing this knowledge annually.

> *"Whistleblowing has been going on for a long time. When I first worked 12 years ago, there was already whistleblowing in the company. When we interviewed it ourselves, the people had already mentioned whistleblowing, so year to year, the basis was that they would remind us to warn us about the whistleblowing." (M_1)*

This suggests that corporate culture and organisational policies play a crucial role in promoting awareness of whistleblowing. When companies actively engage their employees through training and policy reminders, they foster an environment

where whistleblowing is understood and, presumably, encouraged. This proactive whistleblowing education ensures that employees understand the term and can act on it if necessary. This aligns with previous research by Yu, Sirsat, and Neal (2019), which also demonstrated the positive impact of training programs on whistleblowing behaviours, specifically in food safety.

In contrast, some interviewees are less familiar with the term "whistleblowing" but demonstrate an understanding of the concept. For example, an informant admits she "had never heard" the term before the interview. However, she intuitively describes a process of reporting problems that aligns with the principles of whistleblowing.

> *"For me, we must understand who did the wrong thing and why. As far as my experience goes, even if there is a problem, we will discuss whether we should bring the information to the superiors. If we can settle between me and the supervisor, we will try if we take it to the higher-ups." (SHE_1)*

The interviews also reveal various whistleblowing experiences and applications among employees, illustrating the diversity of understanding and practice. One informant initially associates whistleblowing with the Malaysian Anti-Corruption Commission (MACC), indicating a connection between whistleblowing and external regulatory bodies. However, he later discusses its relevance in the context of "food defence," particularly when employees witness acts of "vandalism" or "sabotage" in the production process.

> *"... As an employee on the production floor, he will be a whistleblower when he sees someone doing vandalism, or he puts something in the food before it is processed, so he wants to sabotage. That is what I see in terms of food defence." (D_2)*

This example highlights how whistleblowing can be understood in different contexts, depending on the specific challenges and risks faced by the company. Another notable example is provided by an informant, who initially claims to have "never heard" of whistleblowing but later shares a personal anecdote about reporting a contractor for overcharging. Although this incident occurred outside his workplace, it demonstrates his understanding and willingness to act against wrongdoing. This suggests that even without formal training or policy, individuals may still engage in whistleblowing based on their values and experiences.

> *"I used to make a MACC report regarding the misuse of PTA (Parent-Teacher Association) money.:" (D_1)*

The variability in awareness and knowledge suggests that whistleblowing could effectively safeguard halal integrity across the industry. However, for this potential to be fully realised, it is crucial to continue educating and promoting whistleblowing among all employees, regardless of their background or prior experience. By equipping all employees with the knowledge and tools to report wrongdoing, the industry can better uphold its ethical standards and maintain the trust central to the halal certification. This proactive approach strengthens the integrity of the halal food industry and ensures that its operations are aligned with the highest ethical principles. In addition, Tarjo *et al.* (2018) assert that individuals who know whistleblowing can gain additional insights into whistleblowing. Their behaviour will shift from being unaware to being more concerned about whistleblowers' role in preventing and detecting fraud. The findings indicate that it is necessary to promote awareness about the value of whistleblowing as a tool for preventing and detecting fraud. Similarly, Shonhadji and Maulidi (2021) emphasise the necessity of educational initiatives to enhance understanding and encourage a culture of transparency. Educational programs can help close the knowledge gap by giving employees the information they need to make informed whistleblowing decisions. These initiatives can include workshops, training sessions, and easily accessible resources that explain the whistleblowing process, the legal protections in place, and the importance of reporting unethical behaviours. Organisations can empower their employees to act ethically and support them by investing in such educational efforts.

4.3 Factors influencing whistleblowing intention

The interviews with 16 informants identified a few factors for whistleblowing intentions among employees in halal-certified food companies. This research employed the TPB to determine the influence of the TPB proposition, which consisted of attitude, subjective norm, and perceived behaviour control, in determining whistleblowing intentions. Meanwhile, additional factors identified based on the interviews with informants included organisational support, responsibility as an employee, religious obligation, seriousness of wrongdoing, knowledge, and high position of the complaint recipient. Figure 1 shows the illustration generated by Web ATLAS.ti. It visualises factors influencing whistleblowing intentions among employees in the halal-certified food industry. A detailed discussion of each identified factor is discussed in the following subsections.

4.3.1 Attitude

One of the factors associated with whistleblowing intentions was the attitude of the employees. Attitude constituted one of the elements within the theory of planned behaviour framework. In accordance with Ajzen (2012), attitude represents "the degree to which a person had a favourable or unfavourable evaluation or appraisal of the behaviour in question". The interviews with the 16 informants revealed that the attitude of the employees is inclined to blow the whistle as a means of protecting the organisational interest, public interest, and personal interests. To protect organisational interests, employees felt responsible for protecting the company from incurring losses, facing any legal action, and protecting the company image to ensure the company's long-term success. The following quote describes the attitude of the employees towards the whistleblowing intentions of protecting organisational interests.

Figure 1: Illustration of findings (Web ATLAS.ti).

> *"The goodness is for the company's benefit; for example, we do not want negative things like that. We do not want our company to suffer losses, and we do not want our company to face legal action. It is better to inform early on." (HE_1)*

> *"If it involves dealing with authorities, we want to ensure that the company's image is maintained without any issues. Matters affecting customers' confidence in our product need to be addressed." (SHE_1)*

> *"Goodness, like mine, we already have a pledge form with JAKIM to use only this item, so we just need to update it to maintain the company's image." (HE_2)*

On the other hand, protecting personal interests involves actions and decisions to safeguard one's well-being, goals, and values. Employees seek to protect themselves from being blamed in the event of an incident and to secure their employment. As reflected in the following quotes:

> *"Already advised, but it is still not progressing because later when the employer finds out, there is a fear that we might be blamed. Why not inform early on?" (IA_1)*

> *"There is a merit to it. When the staff reports, he defends himself. He wants his rights." (HE_7)*

Meanwhile, protecting public interest is when employees are motivated by compliance with the law, which prescribes what can and cannot be done within an organisation. Therefore, they feel obliged to blow the whistle to protect the public or general interest. The quotes below illustrate how employees feel about the intention of whistleblowing to safeguard public interests or the customers.

> *"It means it is beneficial for the halal system; we want to ensure the public's trust in that halal certificate, the integrity of the halal certification." (HoD_1)*

> *"Yes, to prevent people from consuming non-halal items, it is to safeguard ours, you know, to protect our customers." (HE_1)*

4.3.2 Subjective norm

Subjective norm is the second component of the theory of planned behaviour. Zakaria *et al.* (2016) explained the concept of subjective norm in their paper. They stated that a person would be likely to perform such an action if they received support from their surroundings, such as family, friends, co-workers, etc., and a person would be less likely to blow the whistle if they lacked support from their surroundings. It was observed through interviews with 16 informants that employees were more inclined to report wrongdoing when they received support from their employers, co-workers, local authorities, and family members. Among this support, employees tended to whistleblower if they received support from their employers, as reporting wrongdoing became less complicated, mainly when their employers were motivated to maintain halal integrity. The employees' perspectives can be seen in the following quotes.

> *"For me, if my staff here, everyone is cooperative and has support from the employer." (HE_2)*

> *"If, for example, in the halal community, our boss is someone motivated and feels a strong sense of responsibility for maintaining halal integrity, then even if there are any issues in production, we would not hesitate to inform our boss." (C_1)*

In addition to receiving support from employers, employees are more likely to consider whistleblowing when their co-workers support them. This is because they feel courageous in whistleblowing, and their co-workers demonstrate greater understanding than their family members. Thus, they feel more confident in engaging with whistleblowing. This is also reported by Tarjo *et al.* (2018) in their paper, where a person's attitude is influenced by subjective norms prevalent within their group. The group also acts as a reference group that shares its views, aspirations, and opinions among its members. From this study, the responses obtained from the informants are quoted as follows:

> *"Usually, it is our colleagues... those who typically provide support, friends from the same department, friends who understand our job tasks." (HE_7)*

> *"True.. true.. when it comes to influences, it is mostly colleagues... they will not act alone; they involve their coworkers a lot." (D_1)*

> *"He feels more courageous when there are friends who support and encourage him; they influence him, and he becomes even braver." (HE_6)*

Furthermore, if management fails to address the wrongdoing internally or fails to take any action, employees tend to blow the whistle if they receive support from local authorities. Some informants noted that by engaging with these officers, they can enquire directly without the need for formality, making it convenient for them to seek advice. The following quotes describe the employee's engagement with external parties, such as JAKIM.

> *"Because we will initially address the internal issues; if the internal processes cannot resolve the problem, that is where I feel going through the authority is the easiest. Sometimes, when subordinates point out the issue, the organisation might take it lightly." (SHE_1)*

> *"I usually refer to external parties, such as Jakim, as well as lecturers." (HE_2)*

> *"Exactly... and let me add, the relationship between government agencies needs to be good, for example, with JAKIM. It is not about giving bribes or anything, but when we have a good relationship, we might be able to; for example, if there is an issue, we can ask directly without being too formal. These relationships, they know the officers." (HE_6)*

On the other hand, few informants expressed their willingness to report the wrongdoing if they had support from family members. They are quoted as follows:

> *"There is also such an influence; sometimes, it may not be significant, but it could be due to the wife, perhaps the husband, or maybe this employee, his parents, and so on. It is like that." (D_1)*

> *"Family could play a role if he stays with his family." (HE_5)*

4.3.3 Perceived behaviour control

The third element of the Theory of Planned Behaviour (TPB) is perceived behavioural control (PBC), which refers to an individual's belief about the ease or difficulty of performing a particular behaviour. Zakaria *et al.* (2016) found that individuals' perceptions of the challenges associated with whistleblowing significantly influence their likelihood of reporting misconduct. While the informants in this study did not explicitly mention their control over whistleblowing, their responses highlighted how perceptions of ease or difficulty, influenced by factors like incentives and workplace culture, can shape their intentions. For example, providing incentives such as financial rewards, food vouchers, and discounts were reported to facilitate whistleblowing behaviour. As one informant stated:

> *"As a representative of the organisation, I feel that it facilitates all staff to report any misconduct within the company. Here, we provide various incentives, such as tokens and free food. We also conduct monthly briefings for all staff to*

address any concerns and involve them in the production process. Additionally, we have a supportive HR team here that can address any issues directly." (HE_5)

Based on interviews with informants, the intention behind offering incentives is to encourage employees to blow the whistle, as it aims to protect the company's reputation or profits. This is reflected in the following quote:

"So, we will offer it to the employees if it can save their dignity or if it can save the company's profits. In the past, they used to receive more, but now it is less due to the two years of COVID-19. Previously, there were incentives; they could purchase products at a discounted price. Then, they would receive financial incentives and money and be sent on trips." (AD_1)

These incentives enhance employees' sense of control and ease in reporting misconduct, aligning with perceived behavioural control (PBC) principles. However, PBC is not determined solely by incentives. Other factors, such as fear of retaliation, unclear reporting procedures, or an unsupportive environment, may reduce employees' intention to whistleblow. When employees perceive they lack the means to report misconduct effectively or safely, their likelihood of taking action decreases. These factors that influence whistleblowing intentions are discussed further in the next section. Thus, the findings suggest that PBC plays a critical role in shaping whistleblowing intentions within the halal food industry.

4.3.4 Organisational support

According to interviews with 16 informants, organisational support is the most crucial factor in motivating employees to blow the whistle. This study defines organisational support as a reporting channel, training, top management commitment, policies, and standard operating procedures. Brennan and Kelly (2007) noted that an auditor training at a company with a robust formal reporting structure for addressing misconduct feels more confident that reporting internally will not harm their career, as large audit firms typically have formal reporting policies. This assurance leads to a higher willingness to report wrongdoing than auditors at smaller firms without such policies. Additionally, Brennan and Kelly (2007) found that auditors' willingness to report wrongdoing increased after proper training. Some informants in this study expressed their readiness to report misconduct if their workplace had a clear reporting channel. These channels can be face-to-face or online, with all employee suggestions or complaints kept confidential. Confidentiality is essential to protect whistleblowers from retaliation. The following quotes reflect employees' concerns about having an appropriate reporting channel:

"..., if I want to become a whistleblower, having the proper channel makes me feel less afraid. We have the correct channel to become a whistleblower, so I am not hesitant. If the company itself provides a channel." (C_1)

"We have a link available for making any suggestions, recommendations, or highlighting any issues you want to bring to our attention. Additionally, every month, we conduct briefings for production staff. If there are any issues you would like to voice, feel free to do so during those sessions, and we will listen." (HE_5)

"To facilitate this, they must provide us with a platform, space, and opportunity to report. For instance, if they allow us to do it online, it would be easier to access the information, making it convenient for us to file reports." (HE_6)

"If I work independently in the factory that I built, I see channels of communication... what is it called... for something, there is a designated channel. As Malaysian citizens, we have channels to voice our opinions, rather than solely resorting to writing on Facebook, for example, on social media. So, we see that there are organised channels." (D_1)

Employees are more likely to report wrongdoing when the employer takes appropriate actions, as the following quotes.

"If the employer is supportive in taking follow-up actions, meaning if the impact is positive, then it becomes easier for us to perform our tasks. It also facilitates the process of making reports." (HE_3)

"It means that when a report is made, and appropriate actions are taken, it boosts our morale." (HE_3)

"Oh, no, I focus more on when we inform the boss; we expect changes. I want to see some changes happening." (SHE_1)

"Exactly, so far, any complaints from customers or staff, the employer takes appropriate action." (IA_1)

The presence of policies and standard operating procedures also helps employees engage in whistleblowing, as described below.

"Oh, yes, our policies are in place. We are currently in the process of documenting anti-bribery measures, for

example. The latest one—even SIRIM has it, right? I forgot the ISO number, but it is related to anti-bribery. So, we actively promote those kinds of things. Moreover, when we conduct management review meetings, we consistently use and implement these measures, taking the opportunity to bring these matters forward." (D_2)

"So, there are various channels for us to discuss; what we have implemented in my factory so far is like this. We have Standard Operating Procedures (SOPs) regarding non-compliance issues, outlining how to report them." (D_1)

"So, when there is support for whistleblower activities, there will be standard in place. There will not be any haphazard or inconsistent actions." (C_1)

Based on the above explanations from informants, employees' intention to whistleblower in halal-certified food companies increases when the company has a proper reporting channel, management takes action for the raised issue, and established policies and standard operating procedures are in place.

4.3.5 Responsibility as employee

According to the interviewed informants, the employee's responsibility was identified as the second highest factor in investigating whistleblowing intention among employees in halal-certified food companies. Employees are responsible for whistleblowing due to their responsibility as a Halal Executive. A halal executive must be a Malaysian Muslim citizen with a background in Islamic studies or undergo halal executive training (Muhammad *et al*., 2020). According to Muhammad *et al*. (2020), the Halal Executive must ensure that any non-conformance raised by the Halal Auditor must be completed and all requirements are fulfilled. All the requirements must be fulfilled to avoid suspension or revoking the halal certificate. Thus, informants feel responsible since they are assigned as Halal Executives and must ensure that any wrongdoing is highlighted to the management. The following quotes explain the Halal Executive's intention to whistleblow.

"Both of them, since we are the ones responsible for taking care of it, if we neglect it, then that is also our fault." (HE_3)

"From what I understand, maybe someone acts as a whistleblower because they believe it is the right thing to do. Their responsibility is to ensure that the wrongdoing does not happen again. So, they should bring attention to the mistake to the management... inaudible." (C_1)

Some informants mentioned that the role of a halal executive is akin to that of an ambassador for the company and to authority. Thus, if they witness any wrongdoing, they feel responsible for reporting it. The quotations describe the employee's opinion as a Halal Executive.

"Yes, wrongdoing remains wrongdoing. Because the impact is directly on us, as I mentioned, in my role as a Halal Executive, I consider my position as a mediator and ambassador for the company and an ambassador to the authority. So, there are many things that we need to be aware of; that role is very crucial." (SHE_1)

"It means he understands his responsibility, serving as a witness to the authority's actions. The authority cannot always be on-site, so the Executive Halal is present daily during office hours. The Executive Halal is responsible; they cannot conspire with the company to commit misconduct." (HoD_1)

As demonstrated by the informants' strong sense of duty as Halal Executives, personal responsibility is a significant factor that positively influences whistleblowing intentions. This finding aligns with Astia Putriana *et al.* (2018), who found that personal responsibility positively affects whistleblowing intentions among civil servants.

4.3.6 Religious obligation

Religious obligation is also one of the factors that contribute to the intention of whistleblowing among employees in halal-certified food companies. The Arabic term 'halal' denotes that something is permissible, allowed, and lawful in accordance with *Shari'ah* Law, as mentioned by Ambali and Bakar (2014). The informants are totally aware of their obligation to adhere to this requirement even though they might face potential job loss to ensure that the food provided to customers is halal.

"We Muslims would not want to sell our products to someone whose halal status we doubt." (HE_1)

"If I were to lose my job, InshaAllah, it is okay. If revealing the information could lead to me losing my job, I think it is better to lose the job than to conspire. If we know something is not halal and still sell it, it is better to resign if necessary." (HE_1)

"Because of my responsibility as a Muslim, as a human, I would not conspire, right?" (AA_1)

"The company owner is a Muslim, so it is a collective obligation (fardhu

kifayah) for us to provide halal products." (HE_2)

"The third aspect is to maintain the integrity of halal because, as Muslims, we are especially particular about the halal aspect." (HE_5)

In addition to maintaining halal integrity, the informants are also concerned about sinning if they refrain from whistleblowing when they become aware of wrongdoing.

“I think it is a matter of sins and rewards, hahaha, because it is related to halal, right? Oh well..., I cannot go into details... At least we know... how to put it... afraid of being involved, afraid of committing sins.” (AA_1)

"People know that the Halal Executive emphasises the element of responsibility; it is not just about reporting to the company, but as a Muslim, their responsibility extends beyond this world to be answered for in the hereafter." (HoD_1)

These quotes highlight the informants' strong sense of religious duty and responsibility in ensuring halal integrity. Phrases like "we Muslims would not want to sell our products...," "it is a matter of sins and rewards," and "afraid of being involved, afraid of committing sins" clearly reflect the informants' religiously motivated desire to uphold halal standards through whistleblowing. These sentiments align with Uys and Senekal's (2014) findings, which emphasised the role of religious values and the conflict between loyalty and ethical principles in whistleblowing decisions. The informants' willingness to prioritise their religious obligations, even at the risk of job loss, demonstrates the powerful influence of religious beliefs on their whistleblowing intentions. This observation is further supported by Mansor *et al.* (2022), who found that religiosity among Muslim auditors enhanced their perceived control and self-efficacy, increasing the likelihood of engaging in external whistleblowing.

4.3.7 Seriousness of wrongdoing

When informants were enquired about whether the seriousness of the wrongdoing would influence their decision to engage in whistleblowing, most answered yes. They are willing to engage in whistleblowing if the wrongdoing impacts the halal status, as they feel a sense of responsibility to guarantee that the final product delivered to customers remains halal. Some informants also expressed a willingness to report to external parties if no action is taken following their internal report. This was evident in the informant’s feedback as follows:

“Certainly, when it comes to halal matters, it is serious. We would not want to encourage others to consume something we know is not halal, especially when we would not consume it. Reporting is necessary.” (AA_1)

“If the severity of the case involves halal integrity, we should report it, especially for critical matters. For example, the use of non-halal items in products— is something we need to take seriously. It does not matter if it is our company or not. That is a grave matter when it comes to critical items.” (HE_5)

“When there is misconduct involving serious matters, such as theft, breach of trust, the introduction of non-halal products without proper certification, clear inclusion of pork content, or the use of prohibited non-halal ingredients, these instances become a compelling reason for me and possibly others to feel responsible for disclosing such matters to the relevant authorities, whether internal or external.” (AD_1)

Some of the informants mentioned that if the matter is not serious and can be resolved internally without the necessity of notifying the management, then whistleblowing is not necessary. They are quoted as follows:

“Serious matters should be reported; if it is not too serious and can be resolved independently, there is no need to report.” (HE_3)

“If the matter can be resolved, especially if it is a minor issue, there is no need to inform, but if it involves authority, it is crucial to update the management promptly.” (SHE_1)

“It depends, not to say we will not file a report, but it depends on the case. We discuss cases that we can discuss; we highlight cases that we cannot discuss.” (M_1)

This emphasis on the seriousness of wrongdoing aligns with existing research, which suggests that the perceived severity of misconduct plays a pivotal role in whistleblowing decisions (Daud & Tumirin, 2024). Employees are more likely to report infractions they deem as having significant ethical or legal ramifications, especially those that could jeopardise halal integrity or consumer safety. This study's findings underscore this notion, as informants consistently expressed a heightened intention to report serious violations, particularly those related to halal non-compliance.

4.3.8 Knowledge

Knowledge also plays a crucial role in influencing employees to engage in whistleblowing. By knowing whistleblowing, they become more ready and aware of the necessary steps to address

the wrongdoing, following the step-by-step reporting procedure.

> *"So, sometimes they know they have findings, but at times, they are unsure about what to do. Ultimately, they become reluctant to act, pretending not to be aware. Perhaps our awareness efforts, as part of the management, should involve providing exposure to what needs to be done and step-by-step procedures. Inform them to make it easier for them to report." (HE_5)*

> *"That is why there needs to be an initial implementation, informing them that whistleblowers are protected. This information must be conveyed first because sometimes, if we do not inform them, they may feel that others can find out when they report, leading to internal conflicts. Even if the action is correct, if there is no protection, information can spread easily, and you know how gossip works. That is what we want to avoid. Once there is a policy in place, there is a systematic process, starting with the review of the report to ensure the accuracy of the information provided." (HE_6)*

The findings of this study align with previous research, demonstrating that knowledge and awareness of whistleblowing mechanisms significantly influence reporting intentions. Aslam *et al.* (2021) suggest that education on whistleblowing can directly foster a stronger sense of moral identity, which in turn motivates individuals to report unethical behaviour. Similarly, Sharif (2015) found that knowledge of legal protections for whistleblowers increases their willingness to report wrongdoing. In the context of this study, these findings emphasise the importance of providing comprehensive whistleblowing training and education to employees in halal-certified food companies, as it could empower them to participate in actively upholding ethical standards and safeguarding halal integrity.

4.3.9 High position of complaint recipient

The high position of the complaint recipient also influences employees' intention to whistleblower in halal-certified food companies because they feel that action will be taken if they report the wrongdoing to someone in a higher position compared to those in a lower position. Furthermore, when a complaint is reported to individuals in higher positions, there is a belief among employees that management takes prompt action. The statements they provided are as follows:

> *"I feel it influences... because depending on the position, for instance, if we report to HR, actions are taken more promptly. If it is the head, the response might be slower. Usually, reporting to the head expedites the process, while going through the hierarchical line might slow things down because it needs to pass through various channels." (HE_5)*

> *"It means that if we inform those lower in the hierarchy, the lower-level individuals may often be unable to resolve the issue. So, what we do is that individuals with authority have a significant influence on the complaint process. If the rank is higher, people are more inclined to file reports with those higher-ranking individuals." (HoD_1)*

This finding aligns with Moberly's (2014) assertion that the recipient of a whistleblower's disclosure significantly influences the whistleblower's subsequent actions and can affect the willingness of others to report concerns. In the context of this study, informants indicated a preference for reporting to higher-ranking individuals, as they perceived them to have greater authority and ability to initiate corrective action. This preference suggests that employees' trust in the effectiveness of the complaint recipient is crucial for encouraging whistleblowing.

5. Conclusion

The results showed varying levels of familiarity with the term 'whistleblowing'. Employees from companies with formal whistleblowing mechanisms demonstrated higher awareness, while others were less familiar with the term but understood the concept of reporting wrongdoing. This suggests that organisational policies and training are crucial in promoting awareness. The findings revealed that employees were more inclined to report wrongdoing when they received support from their employers, co-workers, local authorities, and family members. Additionally, incentives like financial rewards and food vouchers increased the likelihood of whistleblowing. These highlight the importance of a conducive organisational environment.

Besides attitude, subjective norms, and perceived behavioural control, religious obligation emerged as an important factor influencing whistleblowing intentions. Employees' strong sense of religious duty and responsibility in ensuring halal integrity motivated them to report wrongdoing, even at the risk of job loss. Other factors influencing whistleblowing intentions include organisational support (such as a proper channel for reporting), employee responsibility, the seriousness of wrongdoing, knowledge, and the perceived position of the complaint recipient. These findings offer valuable insights for enhancing whistleblowing practices within halal-certified food companies and emphasise the need for further research into the interplay of cultural, religious, and organisational factors in shaping ethical behaviour within the halal industry.

While this study offers valuable insights, it is also important to acknowledge its limitations. The qualitative nature of the research, while allowing for in-depth exploration of employee perspectives, may limit the generalizability of the findings to a larger population. The study's focus on the Malaysian halal food manufacturing sector may not fully encompass the nuances of other halal industries or cultural contexts. The self-

reported data from interviews may also be subject to social desirability bias, where respondents may provide answers that they believe are more socially acceptable than their true beliefs or experiences. Future research could employ mixed-method approaches and expand to different halal sectors and cultural settings to address these limitations and provide a more comprehensive understanding of whistleblowing intentions in the halal industry.

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Catering to Muslim travellers: a review on the value of Muslim-friendly tour guides services

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Abstract

The tourism industry is experiencing rapid growth and is expected to continue expanding. One of the most prominent developments within this sector is the emergence of tour guides in Muslim-friendly tourism, which involves catering to the specific needs of Muslim travellers. Through a literature review, this study aimed to delve deeper into this topic, focusing on the significance of tour guide services within the framework of Muslim-friendly tourism. The review revealed that tailored tour guide services play a crucial role in enhancing the overall satisfaction of Muslim tourists during their travels. These findings have important implications for tour operators and travel agencies, as they can use them to inform the design and marketing of tour guide services tailored to Muslim travellers' needs.

1. Introduction

Tourism fosters cultural exchange, creates connections, and enhances global understanding (Bhuiyan *et al.*, 2011; Aziz, 2018). In recent years, there has been a growing recognition of travellers' diverse needs and preferences, particularly those of the Muslim faith. As Muslim travellers embark on their journeys worldwide, they seek experiences that accommodate their religious requirements, cultural sensitivities, and halal lifestyle (Mahliza *et al.*, 2021). In this context, the role of a Muslim-friendly tour guide emerges as a vital element in ensuring an inclusive and enriching travel experience for Muslim tourists. 'Muslim-friendly tour guide' refers to a knowledgeable and culturally sensitive individual who profoundly understands Islamic customs, practices, and dietary restrictions (Nugroho *et al.*, 2019). These tour guides are equipped to offer specialised services and facilitate a seamless experience for Muslim travellers. However, the importance and impact of Muslim-friendly tour guides have yet to be extensively explored and comprehensively understood within tourism research. By examining the benefits and challenges of this specialised guiding service, the research sheds light on the critical significance of Muslim-friendly tour guides in promoting a more inclusive and welcoming tourism industry.

According to Dahles (2002), tour guiding has a critical role in how a destination place is portrayed in determining the calibre of the visitor experience, the duration of stay, and the subsequent economic benefits for a local community. The tour guide is one of the most crucial aspects of a visitor's experience at a location (Prakash *et al.*, 2010). They assist tourists and help them design their own experiences. Tour guides are front-line employees who present travellers with the 'moment of truth', which can make or break the trip (Zhang & Chow, 2004). Even though guides have been around for more than 2,600 years, they only started playing a significant role in the travel business with the rise of mass tourism (Cetin & Oter, 2016). Today, organised tourism would be very challenging without the assistance of both tour managers and tour leaders (who accompany the group during the travel) as well as tour guides (who welcome the group to the destination) (Cetin & Oter, 2016; Prakash *et al.*, 2010).

This article examines tour guides' distinct contributions and difficulties in catering to Muslim tourists. It also aims to evaluate these guides' influence on Muslim tourists' overall travel experience and emphasise the potential economic and cultural advantages that arise from meeting the needs of this expanding market segment. The review emphasises the importance of integrating Muslim-friendly services into the wider tourism industry to encourage inclusivity and improve the quality of travel experiences for Muslim travellers. It aims to enhance the existing literature by thoroughly reviewing and analysing it. It offers significant insights for tourism workers, policymakers, and scholars interested in promoting a more inclusive and hospitable travel environment.

2. Literature review

To date, the Muslim world population is increasing intensively across the globe, totalling around 1.8 billion followers, thus making Islam the world's second-biggest religion after the Christian religion, Christianity. Due to the upsurge in the number of Muslims, various fields linked to and corresponding to those followers of Islam are expanding, such as the tourism industry. Tourism is also widely affected by religious beliefs, which triggered the emergence of halal tourism (Harahsheh, 2019). Given the Islamic knowledge and awareness instilled in many Muslims in contemporary times, halal tourism becomes necessary for Muslim travellers to fulfil their religious duties wherever they travel.

As one of the service businesses, halal tourism focuses on providing services in the tourist and hospitality industries, specifically lodging, food and drinks, and travel activities. Aziz (2018) mentioned, "All these services are Shariah based with the objectives to indulge travellers who demand halal tourism services". Halal tourism comprises more than tourism activities; it also incorporates many more things, such as the availability of halal food and beverages in the local area and prayer facilities for Muslim travellers to perform their five daily prayers on time. Islam also encourages and inspires its followers to go sightseeing to open their minds and hearts when witnessing God's awe-inspiring and breathtaking creations as a sign of the greatness of God. Thus, this study examines the obstacles and difficulties of catering to Muslim tourists.

Halal tourism is basically in line with Sustainable Development Goal Eight (SDG 8) to promote sustained, inclusive, and sustainable tourism and target 8.9, which states that, by 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products (ONU, 2020). To put it another way, halal tourism stimulates the tourism industry to become more up-to-date and aware of the current needs of people around the globe. In addition, halal tourism also increases job opportunities for the locals while promoting the traditions and cultures of non-specialists to the tourists to enhance communication between people of different cultures as a route towards making the world a better place for everyone. One of the job opportunities offered in halal tourism is that of a Muslim-friendly tour guide.

In addition, specific Islamic services and facilities must be available for Muslim tourists, such as prayer rooms that offer prayers daily and other religious purposes, as mentioned by Battour (2018). To this end, amenities such as these help to put the Muslim traveller at ease, and any place that provides these amenities is likely to be favoured by the Muslim traveller. In a similar study conducted by Battour (2018), the researcher discovered that hotels, airports, and tourist attractions offering prayer rooms and other amenities for Muslims will more often than not target this segment of Muslim tourists and will also have good user ratings.

However, religious aspects are also another very important factor, especially for Muslim tourists, and it can be the availability of Islamic or halal food. This can be especially helpful for Muslim tourists to considerably enhance the experience during a vacation in regions and companies that provide a wide range of halal food options during a vacation trip (Oktadiana *et al.*, 2016). Halal restaurants and food outlets, including hotels and food chains, cater to the needs of Muslim tourists in the form of halal food and local cuisine. This is a good example of reciprocity and beneficial for Muslims and the exchange of culture, as the meals act as a language.

Moreover, places that consider every aspect of the halal culture will help Muslim tourists feel welcomed and comfortable during their stay (Abror *et al.*, 2019). It will also involve providing halal services and amenities, such as ensuring that beachwear is appropriate for Muslim women or having separate play areas for men and women. El-Gohary (2016) mentioned in their study that observing the fundamentals of halal culture ensures that Muslim holidaymakers enjoy their journey without experiencing cultural or ethical battles, ultimately making their travel experience extraordinary.

Conversely, many Muslim travellers actively seek environments that adhere to Islamic principles (El-Gohary, 2016). Destinations that provide such settings are more attractive to Muslim visitors who wish to spend their vacations in places that resonate with their religious beliefs. These areas offer security and comfort, allowing Muslim travellers to relax and enjoy recreational activities without encountering prohibited behaviours (Samori *et al.*, 2016). This aspect of halal tourism also appeals to families and individuals seeking a wholesome and family-friendly atmosphere. By integrating these elements, destinations can effectively cater to the needs of Muslim travellers, fostering a more inclusive and thoughtful tourism environment.

Most travel destinations do not provide complete and perfect services or facilities for Muslim visitors, such as prayer places and halal food. As mentioned above, Muslims have proliferated across the country, which is a significant problem for those who live in or visit countries where the majority of the population is non-Muslim. It may seem unnecessary for predominantly non-Muslim countries to allocate a budget specifically for Muslim travellers' services or products. However, investing in Muslim-friendly services, particularly in the tourism sector, can benefit the entire industry. This is where Muslim-friendly tour guide services play a crucial role, especially in halal tourism.

Despite the widespread presence of tour guides in many developed tourist destinations, it is surprising that the academic tourism community has paid little attention to this phenomenon. Remarkably, there is a lack of literature on the role of tour guides in facilitating cultural understanding despite the limited number of existing publications on this topic. This academic inactivity has been persistent for a long time. In 1985, the Annals of Tourism Research published a special issue on the role of tour guides, with Erik Cohen as the guest editor. However, this publication did not lead to a significant increase in knowledge on the subject. In the editor's page of the issue, Jafar Jafari (1985, p.1) stated that this Special Issue of Tourist Guides encountered an additional obstacle: several promised contributions did not come to fruition. This may be attributed to the theme itself, a topic that has been relatively neglected in tourism studies. There have been few changes since 1985, as evidenced by a thorough literature examination. The textbook Tourism: Bridges Across Continents (Pearce *et al.*, 1998) thoroughly examines and evaluates several aspects of the global tourism sector. However, it fails to address the significance of tour guides in developed tourism.

The role of the tour guide is likely to impact the degree of satisfaction that tourists derive from their tour experiences. On the other hand, Lopez's (1980) study proposes that an inefficient tour guide could potentially negatively affect tourists' overall satisfaction during their vacation.

As known globally, the *Qur'an* and the *Sunnah* of the Prophet PBUH are the primary sources for Muslims in directing their lives from the minor little things, such as how to eat, to the biggest ones, for example, how to perform *Hajj* per both sources. Taking that into consideration, Muslim-friendly tour guide services are a need for Muslim travellers as Muslims are obligated to perform some daily obligations, including food and beverages, which need the help of a Muslim-friendly tour guide when they are travelling. Junaidi (2020) has identified some factors that may affect halal tourism, which include halal foods and general Islamic values. That is to say, the joyful moments that Muslim travellers should enjoy may be struck down by the unavailability of halal foods and difficulties in practising Islamic values during travel. To support the above sentences, "The availability of Halal food and beverages is vital for destinations that target Muslim travellers. It is now common for Muslim tourists to request Halal food and beverages when they visit non-Muslim destinations" (Battour & Ismail, 2016). So, Islam has detailed and specific laws, mainly on foods, such as the prohibition of eating halal animals that are not slaughtered by *Shari'ah* law. So, Muslim-friendly tour guide services will help Muslim travellers seek halal foods and beverages and have a great experience while travelling without worrying about what food is available to fill their stomachs.

As Malaysia is one of the countries with the most significant number of Muslim populations, Muslim-friendly tour guide services should be made compulsory in each country due to Islamic law. According to the holy book of the *Qur'an* and the hadith of the prophet Muhammad, Islamic beliefs strongly encourage believers to travel (Andespa *et al.*, 2020). As a result, there are several provisions regarding Islamic tourism, which are as follows: *mustahsan* (recommended), which is a journey aimed at preaching (*dakwah*) and contemplating the signs of nature that can represent His greatness; *mubah* (permissible), which is a journey aimed at delight and pleasure but without causing harm (sin); although it is not immoral, *makruh* is a journey that should be avoided. In other words, the trip is purely for amusement purposes and serves no religious purpose. Lastly, it is *haram* (prohibited) to travel to commit an immoral act or sin, defy God's rights, and engage in religious festivities, rituals, or beliefs of religions other than Islam. Therefore, it can no longer be denied that Islamic law is one of the reasons why Muslim-friendly tour guide services should be made necessary in each country.

Considering Islam as a comprehensive religion, the notion of halal in the context of tourism demonstrates the participation of Islamic teachings in all aspects of a Muslim's life. For instance, Islam teaches its followers to set Islam as the guideline in living their lives and the Prophet Muhammad PBUH as the role model in leading their lives. Thus, having no facilities for Muslims to practice Islamic teaching may become a hardship. Cultural, social class, reference groups, and family factors partially influence the decision-making process of tourists (Najib *et al.*, 2020). Considering that Islamic teachings have a lot to do with the daily lives of their followers, it is recommended that a Muslim-friendly tour guide exists all around the globe to prevent a negative effect on Muslim travellers' travel experiences during travel. Halal tourism can also accommodate Muslim travellers who want to practice Islamic teachings effortlessly when travelling.

On the other hand, halal refers to the capacity to utilise something to meet physical necessities, such as food, beverages, and medications. Halal also refers to the ability to eat, drink, and perform things under Islamic law and principles (Asa & Azmi, 2017). Halal is a concept that encompasses all elements of life. The term halal is used in a wide range of contexts, including human connections, attire and demeanour, social and business activities, commerce and financial services, investment, and any other parallel using rules and guidelines put out by Islam. All the stuff individuals use in their regular lifestyle must be clean and devoid of doubt, according to Islam. Taking anything, *Subhash* does not always offer calm and tranquillity to one's thoughts and spirits; in fact, it goes against humans or nature, as mentioned (Shaary & Wan Harun, 2021). Muslims are urged to avoid uncertainty, which is referred to as *Subhash*. This is to guarantee that all actions are carried out with confidence. As a result, it is vital to underline that food is an essential topic in Islam, and one must comprehend the halal food industry.

Furthermore, sustainable tourism is considered a commendable approach to tourism from an Islamic perspective (Saffinee *et al.*, 2019). From an Islamic standpoint, sustainable tourism integrates the host and local communities' religious beliefs, practices, and dedication (Mahmood & Nurunnabi, 2019). According to the findings, the local people firmly adhered to religious ideas and dedication, which positively correlated with their welcoming behaviour. The perspective of inhabitants towards tourism development is influenced by Islamic religiosity. This demonstrates that the dedication and devotion of religious individuals may effectively mitigate any harm or damage to safeguard the environment.

In Islam, the forbidden things are minimal, while the allowed things are extensive. There are only a small number of explicit texts in the *Qur'an* and *Hadith* on prohibition, while anything not mentioned in the *Qur'an* and *Hadith* is considered halal and permissible. In this case, the Prophet Muhammad PBUH said: "*What Allah has made lawful in His book is lawful and what He has forbidden is unlawful, and what He withheld is lawful as His favour*." Therefore, it also includes travelling to other countries while enjoying the beauty of Allah's creation. In addition, to be a triumphant Muslim and loved by Allah, it is necessary to follow the straight path by carrying out His commands and abandoning His prohibitions. No matter where the Muslim is, whether at home or travelling, his or her responsibilities must be weighed and carried out diligently.

3. Methodology

The article addresses the growing trend of Muslim-friendly tourism and the role of tour guides in catering to the needs of Muslim tourists. The methodology involves conducting a literature review to provide insights into this niche within the tourism industry. By critically assessing the significance of tour guide services within the framework of Muslim-friendly tourism, the review aims to establish the importance of tailored services in enhancing the overall satisfaction of Muslim travellers. Data collection involves gathering detailed and contextually rich information through a literature review. Researchers actively take notes to capture nuances and critical themes. This review was presented through a narrative framework, incorporating detailed descriptions to illustrate key findings.

4. Findings and discussion

The findings are categorised into various subsections: the expansion of the Muslim population, potential economic and cultural advantages, the role of tour guides, and the Importance of Muslim-friendly tour guide services.

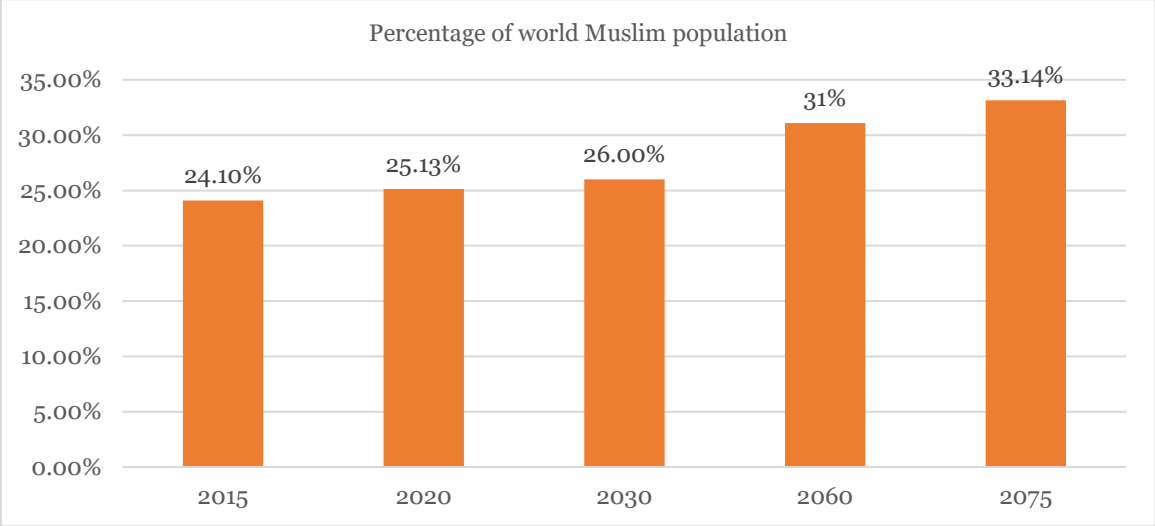

Figure 1:The growth rate of world muslim population (Yan *et al.*, 2017; Hackett & Lipka, 2018).

4.1 Expansion of Muslim population around the globe

Muslim-friendly tour guides are vital as the growing Muslim population worldwide has had a favourable impact on the demand for supply in the Islamic tourist business. Tourism is becoming a popular and profitable global leisure activity for many countries. As Muslims hold the title of the fastest-growing religion in the world, it is indisputable that they hold a significant share of the economic and financial gain for many countries, particularly Muslim-majority countries. The value of Muslim travellers currently represents 10% of the travel market, and spending was USD 126 billion in 2011 and is estimated to reach USD 192 billion by 2020 (Liu *et al.*, 2018). Halal tourism is also required in each country as it benefits Muslim travellers and increases profit in the travel market. Demand for halal tourism services is expected to rise at an astounding rate in the subsequent years, in line with the world's developing population of Muslims, which is expected to reach 2.2 billion in the following ten years (Aziz, 2018). As a result, the Muslim travel industry is predicted to rise rapidly, reaching USD220 billion and increasing to USD300 billion by 2036. Thus, the report makes it irrefutable that halal tourism significantly increases the country's revenue while providing the best facilities for Muslim travellers.

Between 2015 and 2075, Muslims will increase at a rate greater than double as fast as the rest of the world's population. Islam is expected to replace Christianity as the most prominent global religious group in the second half of this century. Hackett and Lipka (2018) stated that the global population is forecast to grow by 32% over the next decade. Muslims are expected to expand by 70%, from 1.8 billion in 2015 to approximately 3 billion in 2060. Muslims accounted for 24.1% of the global population in 2015. They are predicted to make up more than three out of ten of the world's population in 2060 by 31.1%. The Muslim population is proliferating and is expected to reach 26% of the world's population by 2030, as stated in Figure 1. Since Islam is the second largest religion with a steady increase of followers, the growth of this population is estimated to reach 25.13% in 2020 and 33.14% by 2075 (Yan *et al.*, 2017).

Muslim-friendly tour guide services are essential since there is a considerable Muslim population in these rising markets, which is the halal tourism industry. Muslim tourists are increasing faster than worldwide tourists (Liu *et al.*, 2018). COMCEC (2016) reported that the growth of Muslim travellers is a new emerging segment within the travel sector, which will affect the global tourism industry. The fact that Muslims had the youngest median age of 24 among all major religious groups in 2015, over seven years younger than the non-Muslim median age of 32, contributes to the Muslim population's inclination (Research, 2011). Most Muslims will reach the age when they can start having children. This, paired with a high reproductive rate, will hasten the Muslim population's rise. According to a survey by Pew Research (2011), Muslims have even more children than followers of seven other prominent religious groups. The Muslim population's growth and increasing disposable income have resulted in many Muslims travelling for leisure, business, healthcare, and religious reasons. This increase has resulted in Muslim travellers becoming one of the fastest-growing travel segments in the tourism industry, and this number of Muslims across the globe has been the main factor in the need for Muslim-friendly tour guide services. However, it is because tourism is becoming a popular and profitable global leisure activity, and most of the travellers are Muslim, as they are the second largest population and religion in the world.

4.2 The potential economic and cultural advantages

Malaysia is far behind the other countries listed in the Global Muslim Travel Index. Malaysia has been a leader in MFT because the Tourism Ministry for Malaysia has been focusing on the importance of the Muslim Market since 2009. The Islamic Tourism Center (ITC) was also established for the same reason. Many travel service companies have concurred with this, and there are many reasons why this is possible. The country has put much effort into making the place suitable for Muslim tourists worldwide who wish to tour (COMCEC, 2016). Muslim tourism did not imply inventing new or different commodities and services. However, instead of completely changing places and making them suitable for everyone, places would need to add and tweak a few things to suit Muslims. Malaysia originally coined the idea of MFT as the first country to introduce it.

Due to this commitment, the business receives much education, and guidelines and standards have been developed for the most significant services. Because of this, the authorities introduced standard services such as halal food, a place for prayers, and well-equipped washrooms in all the buildings. They have also been well-maintained, especially regarding their physical appearance (COMCEC, 2016).

A value that Malaysia has is its visa-friendly policy, which allows people from the Arab and Gulf States to come into the country without obtaining a visa, and they are allowed to stay within the country for up to three months (COMCEC, 2016). Many Arab and Asian Muslim tourists also enjoy shopping for imported items at Malaysia's new, air-conditioned shopping complexes, particularly for luxury goods.

According to the author, the most significant possibility of economic accumulation is to undertake Islamic tourism. Many member countries of the Organisation of Islamic Cooperation (OIC) are already well-equipped to serve the needs of Muslim travellers, and they may also benefit more from further capitalising on the Islamic tourism industry. Therefore, the diversification of Islamic tourism can be classified as a factor that will contribute to these countries' economic growth and development.

OIC countries can also tap into religious travel by aligning religious travel with cultural and heritage visits to offer innovative and divergent tourist products. Countries that offer Islamic or historical sites will benefit enormously from the chance to enlarge and market the potential of destinations to accommodate Muslim tourists' needs by creating appropriate and specific touristic packages.

4.3 The role of tour guides

Tour guides offer various services, with specific duties varying by speciality. As cited by Prakash *et al.* (2010), these include tourist guides, step-on guides, city guides, interpreters, escorts, tour escorts, and sometimes tour leaders and managers. Several authors have also described tour guides as 'an information giver and fount of knowledge', 'mentors' (Cohen, 1985), 'a mediator' (de Kadt, 1979; Nettekoven, 1979; Pearce, 1982), 'culture brokers' (McKean, 1976) and, 'middleman' (van den Berghe, 1980), etc.

According to Dahles (2002), tour guiding has a critical role in how a destination place is portrayed in determining the calibre of the visitor experience, the duration of stay, and the subsequent economic benefits for a local community. The tour guide is one of the most crucial aspects of a visitor's experience at a location (Prakash *et al.*, 2010). They assist tourists in designing their own experiences. Tour guides are front-line employees who present travellers with the 'moment of truth', which can make or break the trip (Zhang & Chow, 2004). As cited by Cetin and Other (2016), even though guides have been around for more than 2,600 years, they only started playing a significant role in the travel business with the rise of mass tourism. Today, organised tourism would be very challenging without the assistance of tour guides, both tour managers and tour leaders (who accompany the group during the travel) and tour guides (who welcome the group to the destination) (Cetin & Oter, 2016; Prakash *et al.*, 2010).

Although there are various definitions of a tour guide, the International Association of Tour Managers (IATM) and the European Federation of Tourist Guide Associations (EFTGA) have agreed upon the following definition: "A tour guide is a person who leads groups or individual foreign or domestic visitors around the monuments, sites, and museums of a city or region; to interpret the cultural and natural heritage and environment in a way that is inspiring and entertaining in the visitor's chosen language" (EFTGA, 2014). IATM claims that tour guides serve as 'intermediaries' between tourists and the 'unknown' environment, acting as 'buffers' between tourists and the social environment, arranging transportation, interpreting, handling issues, protecting travellers from difficulties, and creating a safe environment for tourists (Zhang & Chow, 2004).

Professionals in the tourism and hospitality industries, often called 'tour guides', escort tourists around popular destinations (Ap & Wong, 2001). Tour guides can take visitors on excursions, museums, and tours of various geographical areas. The best tour guides have a wealth of information about the local culture, history, and practicalities to share with their clients (Cohen, 1985). In order to provide visitors with a memorable experience, many businesses and groups employ guides, some of whom may have specialised knowledge and expertise in the area, culture, or type of recreation for which they are hired.

Moreover, a book that was written by Pond (1993) makes the case that a tour guide should be someone who can take on responsibility, an educator who helps the visitors understand the places they visit, an ambassador who extends hospitality and promotes the destination in a way that encourages visitors to return, a host who can create a comfortable environment for the guest, a tour manager who knows how and when to fulfil the previous four roles, and a facilitator who knows how and when to carry out the previous four roles (facilitator).

Tour guides offer various services, with specific duties varying by speciality. To a greater or lesser extent, depending on factors like group size, mode of transportation, age range, and duration of the trip, tour guides are responsible for providing amusement for their clients, fielding inquiries, and imparting helpful knowledge (Mossberg, 1995; Dahles, 2002). Generally speaking, a tour guide has extensive expertise about a specific location, historical period, or type of activity and is hired to show visitors around and answer questions about it (Prakash *et al.*, 2010). Although a guide's passion for a topic is important, some employers require professional training to ensure that their employees are adequately equipped to provide tourists with valuable and interesting information (Sulaiman *et al.*, 2016; Lin *et al.*, 2017; Guzel and Sezerel., 2020; Pereira, 2015).

According to Cetin and Other (2016), a knowledgeable guide is one of the most significant resources a tourism business can have. A guide can be considered the 'façade' of a firm or business. Many foreign tourists see their tour guides as ambassadors of the city or nation they visit. While the Oxford Dictionary defines a guide as merely "a person who shows others the way," studies have shown that a tour guide's responsibilities are much more expansive. Early research on tour guides concentrated on the function of tour guides. As stated by Cohen (1985), the words 'pathfinder' and 'mentor' are two of the origins of the term 'tour guide'. The leading and mediating domains of the tour guide's duty inspired the two origin lines.

Cetin and Other (2016) stated that Cohen (1985) outlined four fundamental aspects of a tour guide's role. The elements are communicative, social, interactive, and instrumental. The tour guide's most important responsibility is ensuring the excursion is completed successfully as a continuous social venture. Second, the social aspect emphasises the individual's responsibility for the cohesiveness and morale of the travelling company. The third aspect of participation is his or her function as an intermediary between his or her group and the local population, landmarks, institutions, and tourist attractions. The fourth position of the communicative component refers to the tour guide's role in informing tourists about the destination (Cohen, 1985).

4.4 The importance of Muslim-friendly tour guide services

In addition, a study identified four key facets of the job of a tour guide. These elements are communicative, social, interactive, and instrumental (Cetin & Oter, 2015; Cohen, 1985). The instrumental aspect of the tour guide's job, first and foremost, relates to his or her accountability for completing the journey as a continuous social venture. Second, the social aspect is focused on the individual's accountability for the cohesiveness and morale of the travelling party. The third element of engagement is his or her role as a liaison between his or her group and the local populace, landmarks, institutions, and tourist attractions. The fourth position of the communicative component pertains to the tour guide's function of providing tourists with information about the destination (Cohen, 1985).

In addition, Table 1 shows the study conducted by Jamaluddin *et al.* (2023) outlines five fundamental characteristics that must be met in order to be considered a Muslim-friendly tour guide.

Therefore, a Muslim-friendly tour guide is knowledgeable about the Islamic culture and norms and thus able to offer truthful information to Muslim tourists. It means that they know the importance of religious activities and services and can help the visitors to find the right places for praying, halal foods, and other religious needs (Sünnetçioğlu *et al.*, 2020). The cultural sensitivity of a Muslim-friendly tour guide does not only cover adequate and appropriate information forwarding. This is because they are familiar with the culture and religion of the Muslims and can, therefore, provide Islam-oriented information to Muslim tourists, which can be more detailed and informative (Jim, 2008). They know the importance of prayer, fasting, and pilgrimage, for instance, the five times a day prayer, the fasting in the month of Ramadan, and the travelling to holy places. Thus, they can direct the guests to the correct location for prayers by pointing out the nearest mosque or organising suitable praying areas.

Besides, it helps to suggest halal food choices, considering the dietary needs and guaranteeing that Muslim travellers can eat appropriately (Sünnetçioğlu *et al.*, 2020). They can also help with other religious needs, like identifying places for washing (wudu), identifying suitable clothing, and visiting holy places. This way, by ensuring that he or she is culturally sensitive, a Muslim-friendly tour guide makes the Muslim travellers feel welcomed and able to practice their faith while on their tour.

Table 1: Basic characteristics of Muslim-friendly tour guide

No	Characteristic	Explanation	Reference
1	Cultural Sensitivity	They should be aware of the different wants and needs of Muslim travellers and show respect for their beliefs and traditions.	Cetinkaya & Oter, 2017; Lin Lin & Chen, 2017
2	Knowledge of Islamic practices	They can help Muslim travellers and give them correct information about religious duties and things to consider because they understand.	Battour & Ismail, 2016
3	Language skills	Knowing how well tour guides speak English is important because that is the language they use to discuss interesting historical sites with individuals from other countries.	Chanwanakul, 2021
4	Familiarity with halal services	Tour guides should know about restaurants, hotels, and other places that are Halal-certified or Muslim-friendly and can meet the dietary needs of Muslim tourists.	Battour & Ismail, 2016
5	Excellent communication and interpersonal skills	A tourist guide is someone who talks directly to visitors and residents. They must discuss nearby places so the group can understand and connect with them.	Lovrentej, 2015

Furthermore, according to Amr *et al.* (2019), one of the significant issues for Muslims is the search for halal food during travel. A Muslim-friendly tour guide will be able to direct tourists to restaurants or shops that have halal certification and where they can get halal food while they travel. Muslim travellers are usually in the dilemma of searching for an appropriate halal food alternative that respects the Muslim dietary code (Amr *et al.*, 2019).

A Muslim-friendly tour guide solves this by using their understanding of the area and the people they can vouch for to direct tourists to eateries and shops that are halal certified. They are aware of the conditions that govern the cooking of halal foods and will help the traveller to identify places where these conditions are well understood. From local to international, the tour guide can offer various options and meals to meet the customers' needs.

This way, proficiency in the services provided will allow Muslim tourists to enjoy delicious meals without doubts about the food's origin, cooking, and components (Bohari *et al.*, 2013). It gives the illusion of having fulfilled one's taste buds and allows the travellers to get the whole experience of the culture of the place they are visiting. Thus, by providing accurate information on the halal meal options in a given country, a Muslim-friendly tour operator makes the journey enjoyable while ensuring that meal difficulties do not mar the vacation.

Furthermore, a Muslim-friendly tour guide knows that Muslim travellers need to pray and will help them find the nearest mosque, prayer room, or any suitable place to offer their prayers. They can guarantee that the travel itinerary follows the prayer timings, enabling travellers to observe their prayers. Understanding the importance of prayer for Muslim tourists, a Muslim-friendly tour guide takes extra measures to meet their client's religious requirements (Battour, 2016). They are well aware of the surroundings and can quickly point out the nearest mosque or prayer hall where travellers can perform prayers. From having to look for a quiet corner in a heavily populated urban area or look for a mosque in a remote village, the tour guide guarantees that there is always space to pray.

They also pay attention to the prayer timings while preparing the itinerary and give enough time for the travellers to pray without hurrying them or affecting their timeline (Battour, 2016). The tour guide may also inform the travellers of the *Qibla*, which is the direction of the *Kaaba* in Mecca used in the praying. Hence, by taking care of logistical issues of prayer arrangements, a Muslim-friendly tour guide ensures that Muslim travellers can fulfil their spiritual needs and adhere to their religious practices while touring (Battour, 2018). This concern towards prayer facilities not only helps customers feel more comfortable but also reflects the tour guide's awareness of the religious requirements of guests.

Moreover, Muslim tourists usually plan their visits to various historical and religious places (Bhuiyan *et al.*, 2011). Knowledge of Islamic heritage is a key characteristic of a Muslim-friendly tour guide, which enables him or her to offer informative background information and stories when visiting mosques, Islamic landmarks, and historical sites linked to Muslim histories. A professional Muslim-friendly tour guide is conversant with Islamic history and culture, making the trip more enjoyable for the Muslim traveller. They possess a good knowledge concerning the various histories and religions of the regions they visit; thus, they can provide historical and religious information when visiting mosques, Islamic landmarks, and historical places of interest associated with the history of Muslims (Bhuiyan *et al.*, 2011; Abdulhusain *et al.*, 2022). They can recount the tales and events of these sites, the people related to them, and the history of Islamic civilisation.

Their knowledge not only entails facts and statistics but also explains the history and significance of these places (Bhuiyan *et al.*, 2011). Thus, the tour guide informs the Muslim visitors about the history of different places, which allows them to feel more confident, look for their origins, and appreciate the history of Muslims in the visited countries. This is because the guide can enhance the experience of the Muslim traveller by leading them to visit historical mosques, appreciate the architecture and learn about scholars and leaders (Al-Amin, 2002).

However, it is important to recognise that each culture has its own rules and etiquette, especially when dealing with Muslim tourists, as highlighted by Jafari and Way (1994). A Muslim-friendly tour guide is well conversant with Muslim norms and, among other things, will be able to advise tourists on the correct dress code and other conduct to follow within society so as not to offend society in any way. Cultural etiquette is always important, especially in a Muslim country (Zhang *et al.*, 2018). A Muslim-friendly tour guide will provide information about the multicultural population of the country and the general rules that Muslims obey. They are familiar with the correct conduct and acceptable dress code in Islam and the region (Jafari & Way, 1994).

With this knowledge, they will be able to enlighten the Muslim traveller on how to engage the locals appropriately, be polite and avoid offending them. They can help identify the correct dress code for religious sites or conservative regions, which means that travellers will dress modestly and in a culturally appropriate manner (Zhang *et al.*, 2018). In addition, the tour guide can explain how to greet and conduct oneself in the presence of Muslims, their gestures, and social etiquette that tourists should seek to observe while interacting with the locals and fostering goodwill (Arun *et al.*, 2023). By providing information on cultural etiquette, the Muslim-friendly tour guide helps Muslim tourists have a smooth cultural interaction and respect and enjoy their tour experience by being culturally sensitive in different destinations.

5. Conclusion

Briefly, due to the growing Muslim population, Muslim-friendly tour guide services are critical for Muslim travellers. The Muslim world population is rapidly growing worldwide, with around 1.8 billion followers, making Islam the world's second biggest religion after Christianity. As the number of Muslims grows, numerous areas related to and corresponding to those who follow Islam, such as tourism, are expanding. The tourist industry is becoming a successful and profitable worldwide leisure activity for many countries. Because Muslims are the world's fastest-growing religion, it is undeniable that they contribute significantly to many countries' economic and financial growth, especially regarding job oportunities.

Next, the responsibility for Muslims to follow Islamic law while travelling should be taken seriously, as Muslims need to obey

Allah's command. From the most minor details, the *Qur'an* and the teachings of the Prophet PBUH are widely recognised as the primary guides for Muslims in their lives. As for the recommendation, the emergence of Muslim-friendly tour guide services in the halal tourism business requires practitioners to have a clear understanding of the practices of *Shari'ah* compliance as a prerequisite for high-value tourism experiences among Muslim travellers. Thus, the consideration of *Shari'ah* compliance should also be expanded to other related tourism businesses and facilities, such as attractions, airports, visitor information centres, and events. The service provider's duty in constructing the appropriate tourism products and services is to assemble related tourism components to fulfil the Muslim tourist requirements. So, the relationship between tourism and religion can be shown.

Allah has stated in *Surah Al-Mulk* verse 15: "*He is the One who made the earth easy for you, so walk in all directions and eat some of His sustenance. And only to Him are you (returned after) resurrected,*" as well as in *Surah Hujurat* verse 13: "*O humankind, indeed, We have created you from male and female and made you peoples and tribes that you may know one another. Indeed, the noblest of you in the sight of Allah is the most righteous of you. Indeed, Allah is Knowing and Acquainted*." It is crystal clear that tourism is a deed that is vouched for by Muslims who have stable finances to move around and explore the whole universe, which is created miraculously by The All-Mighty. As a result of Muslim sources and guides, the welfare of Muslims is better taken care of, such as having a proper place to worship, having a variety of halal food sources, and spreading Islamic values to non-Muslims throughout the land, sea and air.

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Application of artificial intelligence to toxicological assessment of plant: a bibliometric analysis and future research plans

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Abstract

Artificial intelligence (AI) has gained attention in health science, with significant applications in the toxicological assessment of plants. However, a bibliometric analysis is essential to chart research trends and propose future advancements. This study explores key publications on AI's role in plant toxicity assessment, identifying unresolved issues in pharmacological research. Articles from January 2008 to December 2023 were retrieved from the SCOPUS database, revealing a steady rise in publications, with a sharp increase from 2019 to 2023. A total of 75 research articles were analysed. The articles were categorised into four main clusters: AI applications, drug development, toxicity prediction models, and adverse drug event evaluations. 'AI' was the most frequently mentioned keyword, followed by 'drug toxicity.' Among 64 articles, the USA contributed 29, China 11, India 8, and the UK 4, with the UK having high citation rates. The findings highlight a growing trend toward AI-driven toxicity prediction in drug discovery. However, few studies provide definitive conclusions on AI's potential in this field. The COVID-19 pandemic has heightened interest among researchers and policymakers. This study urges increased government and agency funding for AI-driven toxicity research. Advancing this field will enhance drug safety, reduce harmful testing, and promote sustainable plant use, aligning with SDGs 3, 12, and 15.

1. Introduction

Due to the possible challenges of human biases in toxicological assessment in the plant, there is a dire need in recent times for artificial intelligence to predict potential toxicity and to ascertain off-target outcomes in the pharmacological research workflow. However, there are issues with the threshold of Toxicological Concern (TTC) established to verify the level of chemical exposure between standard chemical toxicity data and below thresholds, which can cause risks to human health (Serafimova *et al.*, 2021; Bury *et al.*, 2021). Further, the purpose of developing the threshold of toxicological concern (TTC) to assess the risk of low-level substances in the diet qualitatively has been attracting the attention of pharmacologists in recent times, triggering the need for artificial intelligence techniques to ascertain the presence of risk substance and the need for comprehensive risk assessment. Therefore, rapid and precise toxicological evaluation of the pharmaceutical products and substances plants is needed to improve medicine production and protect human health (Batke *et al.*, 2021; More, 2019).

Artificial intelligent (AI) is the capacity of the computer to perform human tasks. The foundation of AI applies to the recognition of images in substance. It has developed today into identifying and recognising medical substances in plants and animals to aid the process of complex decision-making, especially in the toxicological assessment of plants for pharmaceutical products (Paul, 2021 & Xu, 2021). Considering the advanced research application of AI in medical sciences, big data in machine learning applications have significantly extended to pharmacological research, such as toxicological assessment of plants for drug manufacturing. Recent evidence has suggested that AI capacity can produce specific and accurate diagnoses of genotoxic impurities in extractables (Bhattamisra, 2023).

Global health issues and the post-COVID-19 era have triggered efforts towards the application of AI in toxicological assessment to derive a 'toxic load' value and relationship that will be representative of all sets of exposure conditions predicted to produce a chosen Specified Level of Toxicity (SLOT) (Busari & Salako, 2024; Sánchez-bayo, 2020). This 'toxic load' can then be used to calculate the risk from the Major Hazard. In recent times, collaborative scientific efforts have developed AI advances to standardise the research process through consolidated standards of reporting trials (CONSORT) and standards for reporting diagnostic accuracy studies (STARD) guidelines. These processes are developed to provide practical guides for applying AI in medical research. There are ongoing studies in using AI for pharmacological development such that the process is completed unsupervised, like the system that works like a 'black box'. Although there are studies about the application of AI to toxicological assessment in plants, little is known about datasets because most AI algorithms work accurately with big datasets to learn from crosscutting information and realities. On the other hand, the available dataset suggests a complication of data labelling and the complexity of the specialised input (Louzao, 2022).

This study, therefore, aimed to conduct a bibliometric analysis and descriptive narrative about existing published qualitative and quantitative work on the application of AI in the toxicological assessment of plants for manufacturing drugs. Amid the scientific survival of the post-COVID-19 pandemic, accurate and sustainable AI toxicological assessment of plants is required for pharmacological research. However, data about the application of AI, like the 'black box' to ascertain plant toxicity, is unresearched; hence, advances in AI and its direction in toxicological assessment for the next decade have not yet been clarified. Thus, we conducted a bibliometric analysis to comprehensively review the AI field in pharmacological research and identify the currently solved and unsolved issues. Furthermore, the study aimed to reveal a research plan and direction for applying AI to the toxicological assessment of plants.

A bibliometric analysis on the Application of AI to Toxicological Assessment of Plants aligns with Sustainable Development Goals (SDGs). It supports SDG 3 (Good Health and Well-being) by advancing safer drug discovery and reducing toxicological risks, SDG 12 (Responsible Consumption and Production) through minimising harmful testing methods, and SDG 15 (Life on Land) by promoting sustainable plant use while protecting biodiversity as posited in the study of Aldousari & Kithinji (2024).

The remaining parts of this paper entail four sections. The first section briefly reviews artificial intelligence and its application to plant toxicological bench research. The second section explicates the methods of data sources and search strategy, while section three describes the search results and key findings. The fourth section presents the conclusion and recommendations for further studies.

2. Artificial intelligent

AI relates to the emulation of human intelligent processes of machines, particularly computer systems. Included in these processes are learning (the gathering of data and rules for utilising that data), reasoning (applying rules for reaching close or exact conclusions), and self-revision (Mohammed & Alkatheiri, 2022).

AI includes many subsets, like machine learning, natural language processing, eyesight, robots, and clever systems. Machine learning, a part of AI, targets forming algorithms that allow computers to learn and make guesses determinations grounded on data (Tripathi, 2023).
AI has applications in nearly all industries, including health care, finance, transportation, and entertainment, along with others. It revolutionises our lifestyles and working systems, improving efficiency, accuracy, and decision-making processes. Nevertheless, AI raises ethical and societal concerns, like job displacement due to automation, algorithm biases, privacy issues, and the potential for misuse in surveillance or warfare. Whilst AI is continuing to advance, it is crucial to address these challenges whilst harnessing its potential for the benefit of humanity (Bajwa *et al.*, 2021).

AI has a variety of applications in medical lab research, offering ground-breaking ways to analyse complicated data, find patterns, and speed up scientific findings. Here are some essential ways AI is utilised in medical bench research:

1) Drug Discovery and Development: AI algorithms can analyse vast datasets to identify potential drug candidates more efficiently than traditional methods. Machine learning models can predict the effectiveness and safety of new compounds, speeding up the drug discovery process and reducing costs (Paul *et al.*, 2021).

2) Genomic Analysis: AI techniques like deep learning analyse genomic data and identify disease-associated patterns. This can lead to discovering genetic markers for disease risk, personalised treatment options, and insights into disease mechanisms (Wardah *et al.*, 2022).

3) Image Analysis: AI-powered algorithms can analyse medical images, such as MRI scans, X-rays, and histopathology slides, to assist in disease diagnosis and prognosis. Deep learning models can detect abnormalities, classify tumour types, and track disease progression accurately (Pinto-Coelho, 2023).

4) Predictive Modeling: AI models can predict patient outcomes, treatment responses, and disease progression based on various clinical and biological factors. These predictive models help researchers understand disease mechanisms, optimise treatment strategies, and improve patient care (Feuerriegel *et al.*, 2024).

5) Drug Repurposing: AI algorithms can identify existing drugs with potential therapeutic effects for new indications by analysing drug databases, molecular structures, and biological pathways. This approach accelerates drug development timelines and reduces costs by repurposing approved drugs for new uses (Prasad & Kumar, 2021).

6) Biomedical Text Mining: AI-powered natural language processing (NLP) techniques extract valuable insights from biomedical literature, including research articles, clinical trials, and electronic health records. This enables researchers to stay updated on the latest findings, discover novel associations, and generate hypotheses for further investigation (Prasad & Kumar, 2021).

7) Personalised Medicine: AI facilitates the development of personalised treatment strategies based on individual patient characteristics, including genetic makeup, medical history, and lifestyle factors. By integrating diverse data sources and employing machine learning algorithms, researchers can tailor interventions to each patient's unique needs, improving treatment outcomes and reducing adverse effects (Johnson *et al.*, 2020).

8) Drug Side Effect Prediction: AI models analyse drug-target interactions, biological pathways, and patient data to predict potential side effects and adverse drug reactions. Early identification of safety concerns enables researchers to prioritise safer drug candidates and mitigate risks during clinical development (Johnson *et al.*, 2020).

AI tools empower medical bench researchers to enhance their processes, delve into intricate biological mechanisms, and expedite scientific breakthroughs. This aims to enhance

diagnostics, treatments, and, ultimately, patient well-being.

2.1 Toxicological assessment of plant and artificial intelligent

Toxicological assessment of plants involves evaluating plant-derived compounds or products' potential toxicity or safety for human and environmental health (Sahil *et al.*, 2021).

AI can contribute to the process of toxicological assessment of plants in several ways, as follows:

1) Data Analysis and Modeling: AI algorithms analyse enormous data sets of plant compounds, including chemical structures, biological activities, and toxicity profiles. Machine learning models identify structure-activity relationships (SARs) and predict the toxicity of new compounds based on similarities to known toxicants or safe compounds (Zhu, 2020).

2) Risk Assessment: AI tools assess the risk of exposure to plant-derived toxins by integrating data on chemical composition, exposure pathways, and toxicological effects. Predictive modelling by estimating the likelihood and severity of adverse health outcomes associated with plant consumption or environmental exposure (Zhu, 2020).

3) Dose-Response Modeling: Unveiling the enigmatic dance of dose-response dynamics lies in AI, where techniques like Quantitative Structure-Activity Relationship (QSAR) modelling emerge as torchbearers. These digital magicians not only forecast the intricate interplay between plant toxins and their doses but also weave a tapestry of safe exposure levels for the diverse inhabitants of our ecosystem. Through their cryptic algorithms, they unearth the elusive toxic thresholds, guiding the hand of regulatory guardians in shaping the safety contours of plant-derived marvels (De Prestis *et al.*, 2024).

4) Biological Assays: Embark on a whirlwind journey through the labyrinth of biological assays, where AI reigns supreme, orchestrating a symphony of high-throughput screening. Within this kaleidoscope of experimentation, plant extracts and their solitary compounds undergo a metamorphosis of scrutiny, traversing realms cellularly and virtually. Behold as automated sentinels decode the language of toxicity, utilising cell-based sorcery, biochemical alchemy, and the ethereal whispers of in silico divination. Their insatiable hunger for data births a cascade of revelations, singling out potential toxicants amidst the cacophony of biological activities. Each compound, a protagonist in this narrative of discovery, awaits its fate, poised for further exploration in the grand theatre of science (Xuelian *et al.*, 2023).

5) Adverse Outcome Pathway (AOP) Analysis: Delve into the labyrinthine depths of Adverse Outcome Pathway (AOP) networks, where AI algorithms wield their cognitive prowess to unravel the cryptic molecular mechanisms underlying the enigmatic dance of plant toxin-induced toxicity. With a masterful stroke, they illuminate the clandestine pathways, unveiling the elusive key events that orchestrate this intricate symphony of harm. This arcane knowledge serves as the cornerstone for crafting targeted testing strategies and forging the frontiers of mechanistically-based risk assessment approaches, where the boundaries of understanding blur and the mysteries of toxicity yield to the relentless march of science (Villeneuve *et al.*, 2024).

6) Ecotoxicological Assessment: Peer through the veils of uncertainty into ecotoxicological assessment, where AI models stand as sentinels at the crossroads of environmental fate and ecological consequence. Within this labyrinth of prediction, they navigate the turbulent currents of aquatic and terrestrial ecosystems, their algorithms weaving a tapestry of potentiality and peril. Through the fusion of chemical fate modelling, ecological exposure assessments, and the elusive whispers of toxicity data, researchers embark on a voyage of discovery, charting the environmental risks that shadow the footsteps of plant products in the realms of agriculture and the untamed wilderness (Ceschin *et al.*, 2021).

7) Data Integration and Knowledge Discovery: AI-powered data integration platforms consolidate diverse sources of information on plant toxicity, including literature databases, chemical databases, and omics datasets. By analysing these integrated datasets, researchers can discover novel toxicants, identify biomarkers of exposure or effect, and uncover associations between plant exposure and human health outcomes (Zhu, 2020).

8) Toxico-genomics and Omics Analysis: Enter the realm of toxicogenomics and omics analysis, where AI techniques emerge as sorcerers of interpretation, wielding the arcane arts of machine learning and network analysis to decode the cryptic language of biological data. Within this tapestry of omics (genomics, transcriptomics, metabolomics), they unravel the intricate tapestry of plant toxicity, peering into the molecular abyss to discern the hidden mechanisms that govern harm. Like celestial cartographers mapping the heavenly spheres, they chart the constellations of biomarkers, illuminating pathways of exposure and susceptibility with an otherworldly precision. Like fragments of a cosmic puzzle, these revelations enrich the tapestry of understanding around plant-chemical interactions, beckoning toward the horizon of personalised risk assessment, where every individual is a universe unto themselves (Xuelian *et al.*, 2023).

In recent years, several notable advances in the toxicological assessment of plants have been driven by technological advancements, methodologies, and interdisciplinary collaboration. Here are some key advances:

1) High-Throughput Screening (HTS) Assays: Behold the marvel of High-Throughput Screening (HTS) assays, where the symphony of automation orchestrates a ballet of rapid testing for toxicity within the bosom of plant extracts and compounds. Through the convergence of cell-based, biochemical, and in silico methods, these assays transcend the boundaries of conventional inquiry, propelling researchers into a realm where efficiency dances hand in hand with

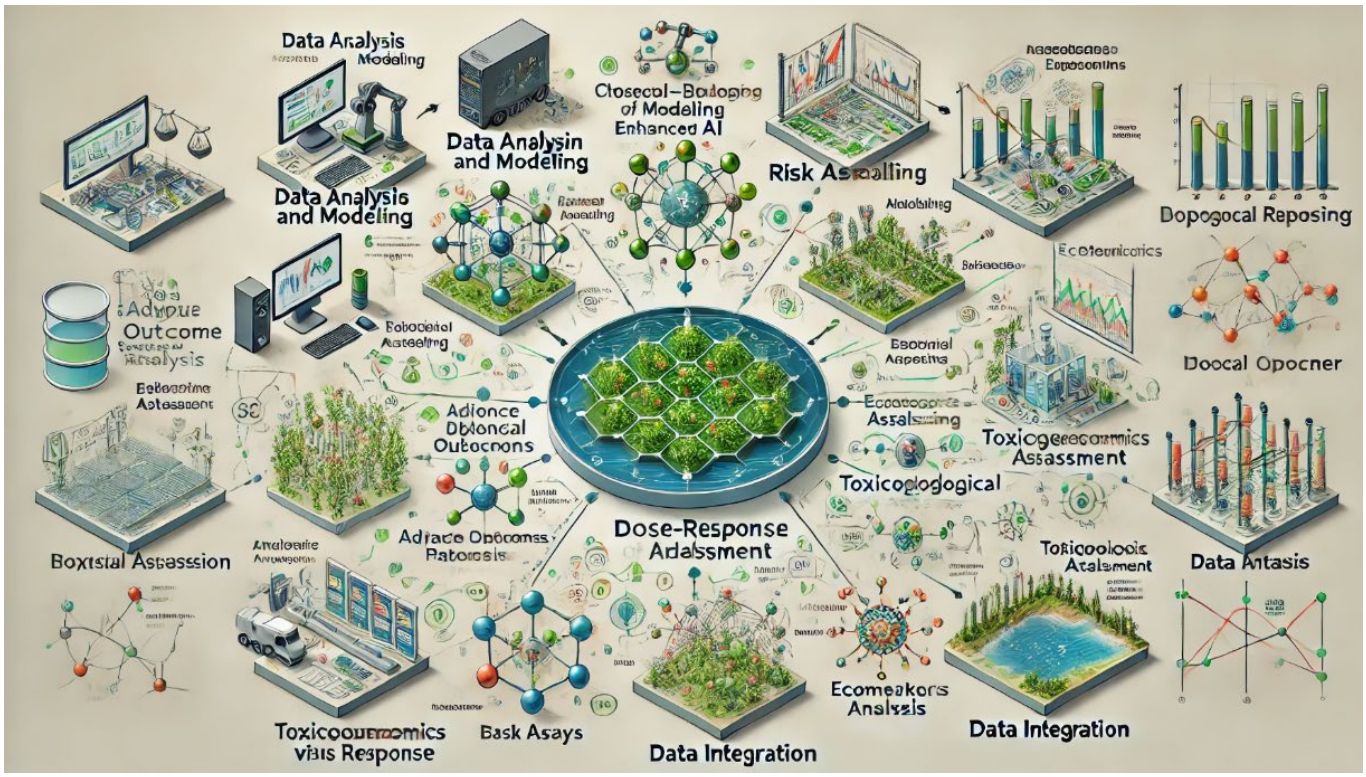

Figure 1: A schematic diagram of the processes involved in the toxicological assessment of plants using AI.

scale. Within the crucible of experimentation, vast armies of samples march in procession, procession, each bearing the potential for revelation or peril. Through the lens of HTS assays, the veil is lifted, hastening the identification of lurking toxicants and unleashing the relentless scrutiny of chemical libraries as the relentless march toward enlightenment gathers pace (Kleinstreuer *et al.*, 2021).

2) Omics Technologies: Peer into the kaleidoscope of Omics Technologies, where genomics, transcriptomics, proteomics, and metabolomics converge to unveil the cryptic tapestry of plant toxicity. Here, within the labyrinth of molecular inquiry, researchers traverse the vast expanse of data, seeking enlightenment amidst the swirling patterns of biological complexity. Through the fusion of Omics data integration and analysis, they unearth the elusive biomarkers of exposure, unfurl the tendrils of toxicity pathways, and sculpt a mosaic of predictive accuracy that transcends the boundaries of conventional understanding (Zong & Guan, 2024).

3) Computational Toxicology: Embark on a voyage through the digital cosmos of Computational Toxicology, where quantitative structure-activity relationship (QSAR) modelling, molecular docking, and toxicogenomics analysis intertwine in a ballet of predictive prowess. Here, within the crucible of computation, researchers wield the tools of virtual inquiry to navigate the labyrinthine pathways of toxicity, charting a course through vast chemical libraries with the precision of cosmic cartographers. Through the alchemy of computational wizardry, they harness the power of data integration to illuminate the shadows of uncertainty, casting a spotlight on the elusive pathways of toxicity with a clarity that defies convention.

4) Multi-Omics Integration: Enter the realm of Multi-Omics Integration, where genomics, transcriptomics, and metabolomics converge in a symphony of biological complexity. Within the tapestry of molecular inquiry, researchers weave a web of understanding transcending individual disciplines' boundaries. By fusing disparate data streams, they unravel the intricate dance of plant compounds and biological systems, illuminating the hidden pathways of toxicity with a clarity that defies expectation (Kleinstreuer *et al.*, 2021).

5) Systems Toxicology: Behold the majesty of Systems Toxicology, where experimental data and computational modelling intertwine in a dance of biological complexity. Here, within the crucible of inquiry, researchers chart the dynamic interactions between multiple biological components, tracing the subtle threads of toxicity across vast biological scales. Through the lens of systems biology, they construct mechanistic models that illuminate the hidden pathways of toxicity, guiding the hand of regulatory decision-making with a clarity that defies convention (Kleinstreuer *et al.*, 2021).

6) Adverse Outcome Pathway (AOP) Framework: Navigates the labyrinth of the Adverse Outcome Pathway (AOP) framework, where toxicological knowledge finds structure amidst the chaos of biological complexity. Here, within the tapestry of regulatory decision-making, researchers chart events from chemical exposure to adverse outcomes, forging

a path through the murky waters of uncertainty. Through the lens of AOP development and application, they translate mechanistic insights into actionable knowledge, guiding the hand of regulatory guardians with clarity that defies expectations (Zong & Guan, 2024).

7) Machine Learning and AI: Witness the dawn of a new era in toxicological assessment, where machine learning and artificial intelligence emerge as titans of predictive prowess. Here, within the crucible of computational inquiry, researchers harness the power of AI to analyse vast and complex datasets, uncovering hidden patterns and associations with a clarity that defies expectation. Through the lens of AI-driven approaches, they illuminate the shadows of uncertainty, guiding decision-makers' hands with a clarity that transcends the boundaries of conventional understanding (Zong & Guan, 2024).

8) Integration of In Vitro and Silico Methods: Peer into the fusion of In Vitro and In Silico Methods, where the strengths of both approaches converge in a symphony of predictive power. Within the crucible of toxicity testing, researchers navigate the complex landscape of compound bioavailability and metabolism, forging a path through the tangled web of biological complexity. Through the fusion of in vitro experimentation and virtual inquiry, they illuminate the hidden pathways of toxicity with a clarity that defies expectation, guiding the hand of decision-makers with a precision that transcends convention (Kleinstreuer *et al*., 2021).

These advances have significantly improved our ability to assess the safety and toxicity of plant-derived compounds, providing valuable insights into their potential health effects and informing risk assessment and regulatory decision-making. Ongoing research efforts continue to advance the field, driving innovation and enhancing our understanding of plant toxicology.

3. Methods data sources and search strategy

Two authors of the research team screened articles published from 2008 to 2023 in the SCOPUS core collection database for bibliometric analysis.

The study search employed the strategy of the PICO framework. P— population/problem refers to the preclinical toxicity testing of new compounds on animals for the drug development process. In—intervention, our study comprised various AI methods and machine-learning technologies. C—Comparison indicated the difference between AI assistance and physical administration of a substance to the animal. O—outcome, which outlined the results of the physiological effects of AI on the toxicological assessment of plants.

The search strategy was based on information from previous studies and experts' opinions. We used related and specific keywords related to toxicological assessment ('toxicological assessment / toxicological assessment', 'plant toxicity', 'plant toxicity testing', and 'administration of plant substance in an animal'), AI technologies ('artificial intelligence', 'AI', 'machine learning'), and plant substance in animals ('drug toxicity', 'toxicological assessment') in the SCOPUS publication.

We downloaded publications from the bibliometric analysis and extracted the dataset based on the publication details, such as authors and titles. This study employed standard weight attributes link and the total link strength attribute of the articles. The weight attributes describe the frequency of links between items and the total strength of the links between the items.

3.1 Inclusion and exclusion criteria

The articles for bibliometric analysis were restricted to original English-written articles. The exclusion criteria were (I) non-English written documents and (II) documents classified as nonoriginal articles.

3.2 Statistical analysis

The study used the intrinsic functions of the SCOPUS core collection database by IIUM to describe the basic features of the detected publications. VOS viewer (version 1.6.19; for Microsoft Windows) was used to construct and visualise co-occurrence networks of co-authorship, co-occurrence, citation, and keyword search. The VOS viewer defined keywords that occurred more than five times as high-frequency keywords. VOS viewer clustering algorithms were used to calculate all the algorithms based on previous guidelines (10).

4. Results

4.1 Publications output

A total of 77 eligible publications were selected, of which 406% were original articles, 233% were reviewed, 111% were conference papers, 29% were book chapters, and 14% were other types of articles. It should be noted that almost half of the eligible publication's articles (34.6%) were published between 2021- 2023. Ultimately, 803 English-written research articles were included in the bibliometric analysis (Figure 1).

4.2 Growth trend of publications

A steady growth in the number of publications in this field between 2014 and 2020 was detected, while the search showed a rapid increase in the number of articles in this study area from 2021 to 2022 (Figure). The total number of articles published before 2021 was (228) while 306 were published between 2021 and 2022 alone. This shows that the two-year publication was about 62 more than the range of research in this field between 6 years. The search detected about 74 countries' contributions to the field of artificial intelligence/machine language in toxicological assessment-related research. The United States of America (USA) has the most publications of about (n=249) articles, followed by China (n=127), India (n=93), and the United Kingdom (n=76), respectively. At the same time, other countries, mainly those in Europe and Asia, had the remaining publications. Keyword searches identified by the VOS viewer are based on the citation index service of the SCOPUS core collection database. Finally, 1415 keywords were identified from the included articles, with 169 meeting the thresholds based on 3 occurrences. Among them, 27 keywords were high-frequency and included in the analysis.

Bibliometric analysis of keywords

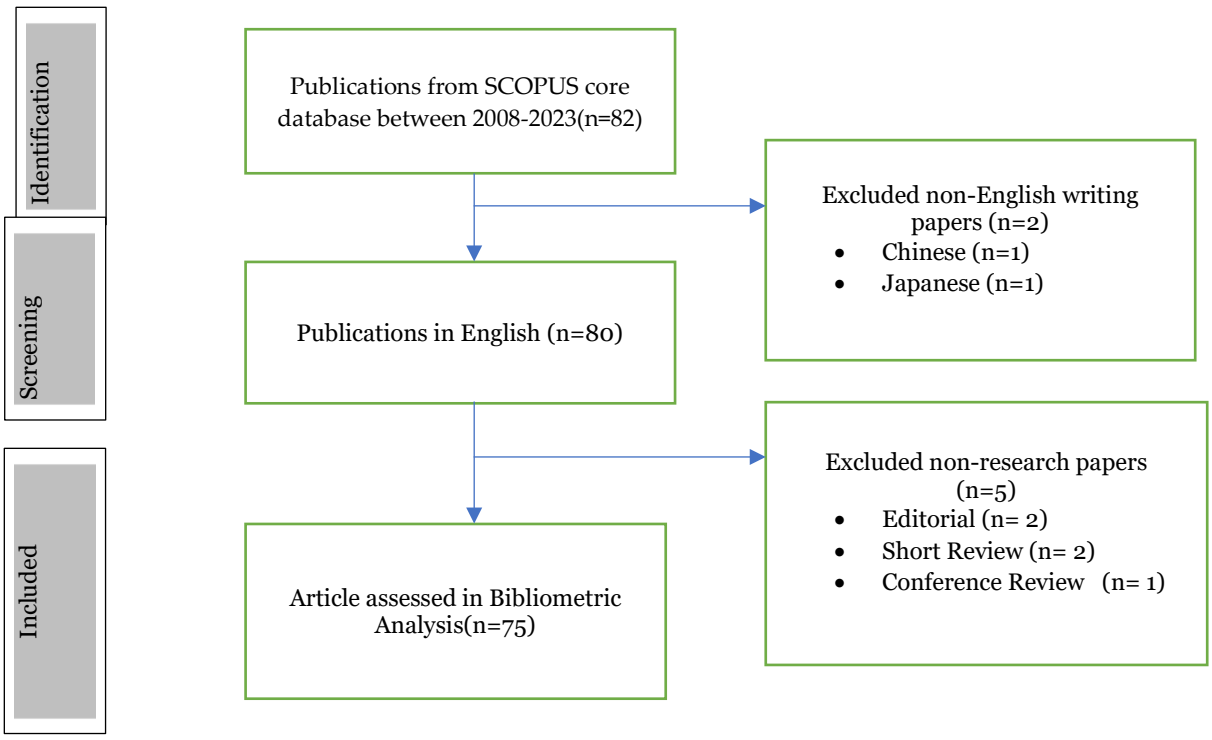

Figure 2: Flow diagram of the article selection process: SCOPUS.

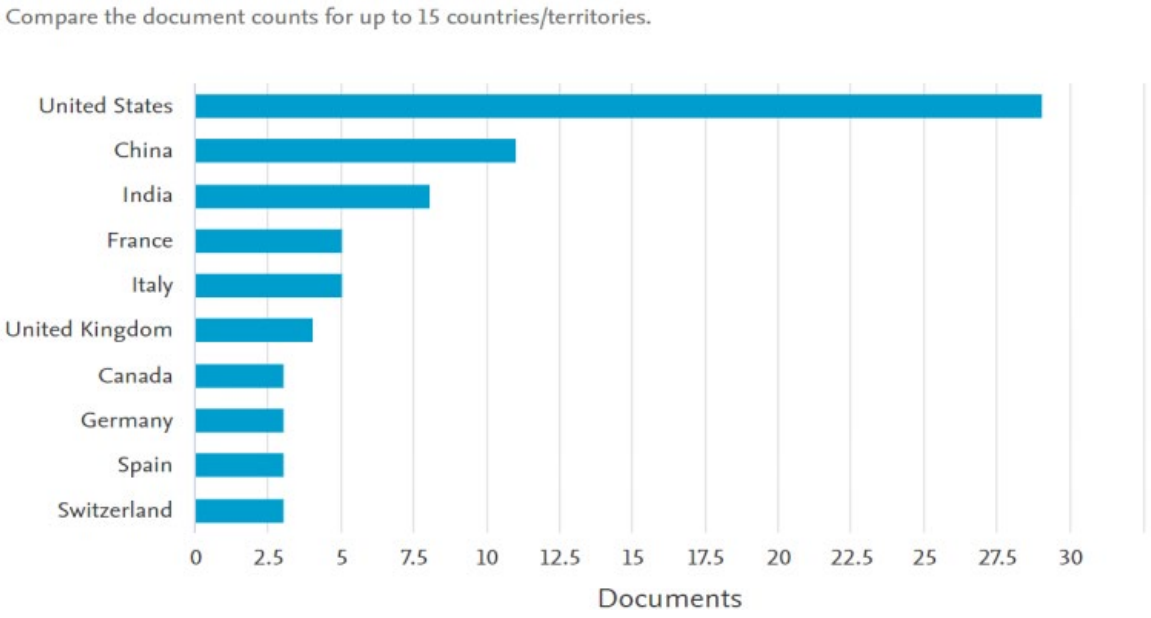

Figure 3A: Comparison of the documents based on countries.

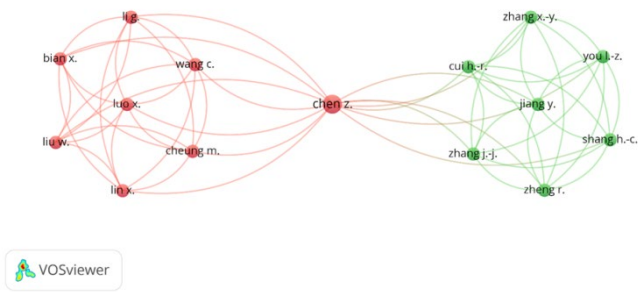

Figure 3B: Co-authorship and complete counting.

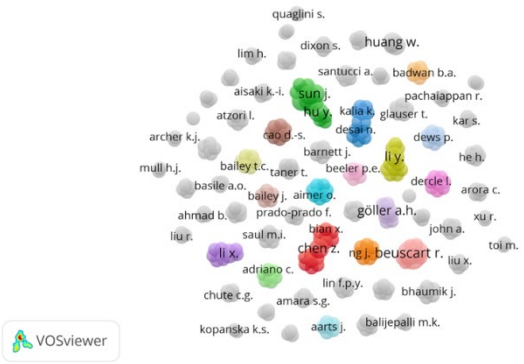

Figure 4A: Co-authorship and complete counting.

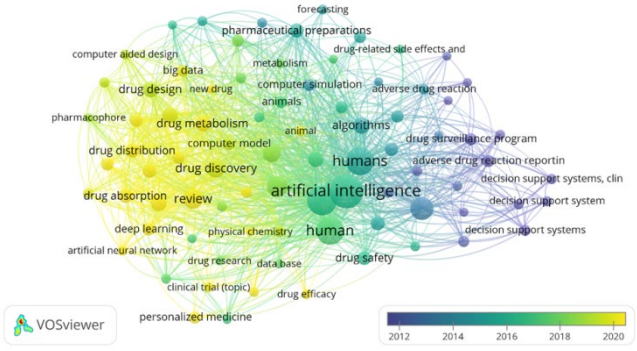

Figure 5: Keywords co-occurrence with full counting method.

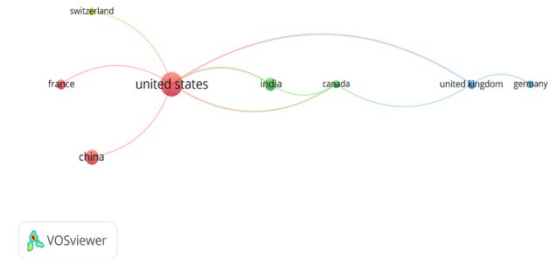

Figure 6: Co-authorship by countries with the whole counting method.

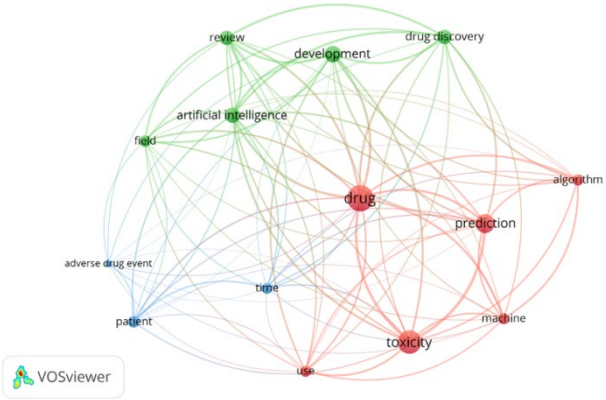

Figure 7: Kinds of research cluster.

5. Discussion of findings

Co-authorship and complete counting found a particular author repeatedly having co-authorship on the subject matter. This means that when examining co-authorship and conducting a comprehensive count of occurrences, it was discovered that a specific author repeatedly collaborated with others on the same topic or subject. This phenomenon is crucial in bibliometric analysis as frequent co-authorship reflects intellectual leadership and collaboration networks. The whole counting method, which equally credits all authors, highlights the recurrent contributions of a specific author quantitatively (Lim & Kumar, 2024).

In co-occurrence with full counting search, the keywords artificial intelligence, human, drug safety, and pharmaceutical preparation are in order of the highest frequency occurrence. This indicates that during a co-occurrence analysis alongside a full counting search, the keywords 'artificial intelligence', 'human', 'drug safety', and 'pharmaceutical preparation' appeared most frequently, with their order based on their frequency of occurrence. Using the complete counting method, co-occurrence analysis effectively identifies dominant research topics by assigning equal weight to each keyword occurrence, reflecting their significance in shaping research trends (Senthil *et al.*, 2024).

According to the search of different research clusters, the order of highest occurrence is 'drug' prediction, toxicity, and artificial intelligence, and drug development is the keyword with the highest clusters. This suggests that in a search focusing on types of research clusters, the keywords with the highest occurrence were 'drug prediction', 'toxicity', and 'artificial intelligence', with a particular emphasis on 'drug development' as the keywords with the highest clusters. According to Chen (2012), these terms strongly emphasise AI-driven predictive models for toxicity and drug discovery, reflecting significant advancements in these areas. Such keyword clustering is instrumental in identifying research priorities and guiding interdisciplinary collaboration in pharmacological development.

These results suggest a strong focus on collaborative authorship within a particular subject area, possibly in academia or scientific research. Additionally, they indicate that specific keywords like 'artificial intelligence', 'drug safety', 'pharmaceutical preparation', 'drug prediction', 'toxicity', and 'drug development' are significant topics of interest within this research context. This information could imply trends in research priorities, potential areas of expertise for the authors

involved, or emerging themes in the field. Collaborative keyword search trends indicate a shift toward AI-driven approaches in pharmacology and safety assessment, aligning with broader healthcare goals, while the frequent occurrence of specific keywords signals author specialisation and highlights emerging themes that could shape future developments in the field.

The Vosviewer analysis shows that the term: 'AI' has the highest frequency keyword (73 occurrences, 848 total links strength) while the 'drug toxicity' keyword (56 occurrences, 767 total link strength) was the second most frequent keyword, followed by human, machine learning, and drug discovery. Based on 75 academic articles, the United States of America (USA) had the highest frequency of 29 documents with (675 citations and 9 total link strength), followed by China with 11 with (223 citations and 9 total link strength) and India with 8 (118 citations and 9 total link strength) respectively. The documents from the United Kingdom have only 4 articles, with (253 citations and 4 total link strengths).

6. Conclusion

Recent attention has been drawn to the utilisation of AI in forecasting drug toxicity, particularly heightened during the COVID-19 crisis. Encouraging collaborative financing between governmental bodies and organisations is imperative to delve deeper into AI's advancements in this domain. The burgeoning research underscores its potential in medical sciences and human welfare. The application of AI to the prediction of drug toxicity in drug discovery and development is a research field with great potential. In the post-COVID-19 era, there is a dire need to enhance cooperative policy support between government agencies and funding for AI in drug development. Although growing numbers of studies focus on decision-making using AI applications in drug toxicity and prediction models in drug development, findings suggest that researchers in a particular field are teaming up frequently, indicating a strong collaborative culture. Moreover, specific topics like artificial intelligence and drug safety seem to be hot research areas, likely driving advancements in related fields such as pharmaceutical development.

Therefore, this research contributes by identifying key trends in the application of AI in pharmacology, particularly for drug safety and development. It highlights emerging themes and areas of expertise, revealing shifts toward AI-driven solutions and emphasising collaborative authorship. These insights guide future research priorities and potential innovations in healthcare.

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